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Modeling and simulation of fleet air defense systems using EADSIM

Bourassa, Neil Robert.

Monterey, California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL
Monterey, California

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Modeling and Simulation of Fleet Air Defense Systems Using EADSIM

by

Neil Robert Bourassa

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Thesis Advisor: Robert E. Ball

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Modeling and Simulation of Fleet Air Defense Systems
Using EADSIM

by

Neil Robert Bourassa
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1982

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Author: [redacted]
Neil Robert Bourassa

Approved by: [redacted]
Robert E. Ball, Thesis Advisor

[redacted]
William B. Colson, Second Reader

[redacted]
for Daniel J. Collins, Chairman, Department of Aeronautics
and Astronautics

ABSTRACT

The goal of this thesis is to develop a capability to simulate naval anti-air warfare (AAW) systems at the Naval Postgraduate School (NPS). Students in many curricula at NPS can use such a model in thesis research or course work related to air defense. Examples of courses in the Department of Aeronautics and Astronautics in which there is a use for AAW simulation are AE3705 "Air Defense Lethality" and AE3251 "Aircraft Combat Survivability". The Extended Air Defense Simulation (EADSIM) was selected as the model to acquire and install on the Silicon Graphics computer workstations of the Computer Center Visualization Laboratory. EADSIM was developed by Teledyne Brown Engineering for the U.S. Army Space and Strategic Defense Command, and is a powerful analysis tool that can model many aspects of air warfare. The author has used EADSIM to develop AAW and Strike Warfare scenarios for use in AE3705 and AE3251. These scenarios required the creation and modification of platforms within the graphical user interface to simulate naval units. These scenarios can be run and displayed as animated playback files for analysis. In addition, the EADSIM weapon performance model was studied. The default values for weapon systems probability of kill (P_K) were modified, and the results were examined to determine the overall effect of P_K within a simulation.

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TABLE OF TERMS AND ABBREVIATIONS

AAA - anti-aircraft artillery.

AAM - Air-to-air missile.

AAW - Anti-air Warfare.

ACES/Phoenix - Adaptive Combat Environment System, another computer model at NPS.

ADA - Air Defense Artillery.

AFIT - Air Force Institute of Technology.

AFSAA - Air Force Studies and Analysis Agency.

AOI - Areas of Interest.

ASCM - Anti-ship cruise missile.

ATC - Advanced Technology Center (U.S. Army).

AWACS - Airborne Warning and Control System.

C - The computer language in which EADSIM is written.

C^3I - Command, Control, Communications, and Intelligence.

CAA - Concepts Analysis Agency (U.S. Army).

CAP - Combat Air Patrol.

CCB - Change Control Board.

CNA - Center for Naval Analysis.

CD-ROM - Compact disk read only memory.

CG - Guided Missile Cruiser.

CV - Aircraft Carrier.

DD - Destroyer.

DDG - Guided Missile Destroyer.

DMA - Defense Mapping Agency.

DTIC - Defense Technical Information Center.

EADSIM - Extended Air Defense Simulation, the topic of this thesis.

EADTB - Extended Air Defense Test Bed.

EW - Electronic Warfare.

FEZ - Fighter Engagement Zone.

GAFMS - Ground Attack Fighter Bomber Model Software.

GCI - Ground Controlled Interceptor.

GUI - Graphical User Interface.

IFF - Identification Friend or Foe.

IOC - Initial Operational Capability.

IR - Infra-red.

IRIX - Silicon Graphics version of UNIX.

JADO/JEZ - Joint Air Defense Operations/Joint Engagement Zone.

JCS - Joint Chiefs of Staff

JTIDS - Joint Tactical Information Distribution System.

MDS - Minimum Detectable Signal.

MEZ - Missile Engagement Zone.

MICOM - Missile Command (U.S. Army).

Monte Carlo - A method of conducting a simulation.

NAVAIR - Naval Air Systems Command.

NAWC - Naval Air Warfare Center.

NSWC - Naval Surface Warfare Center.

NPS - Naval Postgraduate School.

NTU - New Threat Upgrade.

P_K - Probability of kill.

P_{KSS} - Single shot probability of kill.

P_S - Probability of survive.

PTOS - Patriot Tactical Operations Simulator.

RAM - Random access memory.

RAM - Rotating Airframe Missile.

RCS - Radar Cross Section.

ROE - Rules of Engagement.

Rule Set - A method for modeling different types of platforms within EADSIM.

SAM - Surface-to-air missile.

SCR - Software Change Request.

SCRB - Software Configuration Review Board.

SEAD - Suppression of Enemy Air Defenses.

SGI - Silicon Graphics Incorporated.

SM-2 - Standard Missile 2, the primary AAW weapon of the U.S. Navy.

SNR - Signal-to-noise Ratio.

SSDC - Space and Strategic Defense Command (U.S. Army).

SURVIAC - Survivability/Vulnerability Information Analysis Center

TBE - Teledyne Brown Engineering, prime contractor for EADSIM

TBM - Theater Ballistic Missile

TBMD - Theater Ballistic Missile Defense.

UNIX - A common operating system under which all computer workstations run

Wild Weasel - A SEAD aircraft.

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I. INTRODUCTION

A. BACKGROUND ON AIR DEFENSE MODELING

Air defense, a critical aspect of modern combat, is defined in the JCS Dictionary as

> ...all defensive measures designed to destroy attacking enemy aircraft or missiles in the earth's envelope of atmosphere, or to nullify or reduce the effectiveness of such an attack. [Ref. 1]

Anti-air warfare (AAW) is the term used by the United States Navy for air defense and, in the context of fleet operations, is an entire warfare area. The U.S. Navy's definition of AAW is:

> ... that action required to destroy or reduce to an acceptable level the enemy air and missile threat. It includes such measures the use of interceptors, bombers, antiaircraft guns, surface-to-air missiles, electronic countermeasures, and destruction of the air or missile threat both before and after it is launched. Other measures which are taken to minimize the effects of hostile air action are: cover, concealment, dispersion, deception (including electronic), and mobility. [Ref. 2]

For the purpose of this thesis, the terms AAW and air defense will be considered to be synonymous.

To the warfare qualified Military Officer, the study of air defense is highly pertinent. Consequently, there exists a need for an extensive anti-air warfare computer model at the Naval Postgraduate School (NPS). This model should be incorporated into the NPS/NAVAIR Survivability and Lethality Assessment Center (SLAC). The SLAC currently contains most of the standard programs for assessing the survivability of Blue aircraft against a Red air defense. However, it lacks a model for Blue AAW against a hostile air attacks. Such a model can also be used in many different courses of study.

Curricula where air defense modeling may be used include Aeronautics, C^3I, Operations Research, and Combat Systems Engineering.

Air defense modeling can be described as the simulation of actions, events, and encounters between computer generated aircraft, sensors, targets, and weapon systems. A variety of air defense computer models have been produced by various branches of the Department of Defense. Most of these models are described in the *Catalog of Wargaming and Military Simulation Models* [Ref. 3] which lists the models, simulations and war games used throughout the Department of Defense. A model is "a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process." [Ref. 4] A simulation is "a method for implementing a model over time." [Ref. 4] It also is "a technique for testing, analysis, or training in which real-world systems are used, or where real world and conceptual systems are reproduced by a model." [Ref. 4]

Models can range from high fidelity, single target (one-on-one) models, to lower fidelity but complex (many-on-many) simulations. Some models concentrate on a specific aspect of AAW, such as missile fly-out, with very high fidelity. Others, such as theater level simulations, are concerned with a higher scope of conflict. In this case, an entire battlefield may be modeled, with the associated engagements and outcomes determined by a particular scenario run.

All services have developed a variety of air defense models for their own use, some are used jointly. Different levels of fidelity are required based on the user's needs. No one model can do everything for everyone. Thus, specific models have been produced for specific tasks. The needs of the user determine the scope and fidelity of the model.

B. MODELING REQUIREMENTS AT NPS

At the Naval Postgraduate School, students often need to evaluate the effectiveness of a specific weapon system against a certain target. In the realm of air defense, one is concerned with the effectiveness of friendly anti-air weapons against an airborne threat. This topic is covered in great detail in the course AE3705 "Air Defense Lethality". Other students may be concerned with the survivability of friendly aircraft against a hostile air defense. This is addressed in AE3251 "Aircraft Combat Survivability". In both courses, the use of an air defense computer model is an assigned homework problem. The Air Defense Lethality problem deals with the effectiveness of surface-to-air missiles (SAMs), anti-aircraft artillery (AAA) and small arms fire against an attacking aircraft. The Aircraft Combat Survivability problem looks at the survivability of an aircraft attacking a target defended by hostile SAMs and anti-aircraft guns.

The computer simulation currently used in the class assignments resides in the NPS mainframe and is somewhat out of date. Newer computer simulations are now available that take advantage of the processing power and graphical user interface (GUI) of today's computer workstations. Many of the air defense simulations listed in the *Catalog of Wargaming and Military Simulation Models* have been written to run on desktop workstations. As a result, finding the appropriate model to use at NPS not only requires finding the appropriate software, but also the available computer system in which to run it on. To complicate the problem, the software may have certain hardware requirements. This may be a function of random access memory (RAM), storage capacity (hard disk), or graphical capability of the computer. Fortunately, the *Catalog of Wargaming and*

Military Simulation Models lists the system requirements along with the model's description.

C. ISSUES THAT IMPACT AAW MODELING

To facilitate the selection of an appropriate air defense model for use at the Naval Postgraduate School, one must consider some relevant issues. In this post Cold War era, the military is faced with an ever shrinking defense budget. Consequently, less expensive methods must be developed to train and educate the military. In addition, procurement of new weapon systems will under come much more scrutiny as compared with projects of the previous decade. Computer modeling and simulation are powerful and valuable tools, and are an available method to investigate a problem and come to a logical solution. In almost every case, a real world scenario can be simulated on a computer at a greatly reduced cost.

1. Current Military Operations

The first issue to be discussed is the climate of today's military operations. Besides stopping the spread of aggression as in Desert Shield/Desert Storm, the military may be called upon to act as a peacekeeping force. This is exemplified by American participation in U.N. sponsored intervention in Bosnia. Efforts like the humanitarian aid in Somalia will also continue as the need exists. Furthermore, the protection of vital national interests and those of U.S. allies are important roles of the military.

The U.S. Navy's white paper, *From the Sea*, describes a naval force operating in littoral waters [Ref. 5]. Ships operating in these coastal waters may be subject to attack by tactical jet aircraft and sea-skimming anti-ship missiles. As a force, the Navy must

be able to deal with such threats and continue with the mission at hand. Developing the ability to model such a scenario is a key goal of this project.

2. Current Threats and Threat Areas

The military is no longer operating in a bipolar world. As a result, the threat of hostile emerging nations is real. Such a threat can be generic, but the systems that compose that threat are state of the art. An example of a specific threat to naval forces is the anti-ship cruise missile. It is possible to build a data base that contains known or potential threats and incorporate these into the simulation. Such a capability is essential if the model is to be flexible and useful.

The current geopolitical situation shows that the Middle East will continue to be a major concern. Other potential threats include the Korean peninsula and the Balkans. A theater level model must be able to simulate any of those regions as well as other area on the globe. Again, flexibility of the model will make it a more useful tool.

3. Future Threats

The threats that may present themselves today may not necessarily be the threats of tomorrow. An example of the proliferation of a new threat is the number of countries that have obtained a Theater Ballistic Missile (TBM) capability. Future threats may include low observable missiles and aircraft, advanced radar systems, and directed energy weapons. The ability of a model to grow, adapt and be capable of simulating future threats also adds to its usefulness.

4. Expected Value Models versus Monte Carlo Models

The specific outcome of any air defense scenario is unpredictable or random, (e.g. one aircraft may be killed or five aircraft may be killed in a given scenario). There are two methods of simulation for this random process, the Expected Value method and the Monte Carlo method. In the Expected Value method, the simulation is run once using individual weapon kill probabilities, and a prediction is made with respect to the probability of specific outcomes (e.g. a 55% probability one aircraft and a 10% probability five aircraft are killed). The Expected Value of aircraft kills for this scenario is determined from the descrete probability distribution function of aircraft killed, (e.g. the expected number of aircraft kills is 2.3). Expected Value simulations use a set of probabilities for the different factors being modeled and the model is run only once. With an expected value model, identical results will be produced each time the simulation is conducted.

In the Monte Carlo method, the weapon kill probabilities are used in conjunction with random draws to determine a "yes or no" outcome for each encounter (e.g. the aircraft is killed). A Monte Carlo simulation consists of running the model multiple times for each scenario. Each "run" uses a different random number seed, which gives different results for each simulation of a particular scenario (e.g. four aircraft are killed in run one and two aircraft are killed in run two). Combining the results from each Monte Carlo run provides the user with a composite set of results. These results may be plotted on a histogram for further analysis.

5. Other Required Capabilities

The capability to represent both surface ships and naval air units is essential for the modeling of naval AAW. Representation of ground forces, although not necessary, is recommended. A graphical output for analysis is strongly desired, as is the ability of the model to do Monte Carlo simulations. Two way simulations (Red-on-Blue and Blue-on-Red) is desirable, as is the modeling of Command, Control, Communications, and Intelligence (C^3I). Other desirable features include a missile fly-out model where the trajectory of the weapon is calculated, Electronic Warfare (EW), and terrain modeling.

D. SELECTING A MODEL

1. Sources

In order to select the most appropriate air defense model to use at NPS, the author investigated all possible sources. The *Catalog of Wargaming and Military Simulation Models*, which has inputs from many of the analysis agencies in the various defense establishments, independent contractors, and research organizations, was the primary source. Other sources of information included the research desk at the Dudley Knox Library of NPS. An internal computer search yielded listings of documents held within the library, including completed thesis work on similar topics [Ref. 6]. An external computer search through the *Dialog* Service, yielded public domain material on the topic of air defense models and simulations [Ref. 7]. The search also included listings of related information from NATO allies through international access.

2. The Available AAW Models

Appendix A lists a selection of AAW models and simulations that were considered to be suitable for this project. Although it is not a comprehensive list of AAW simulations, it contains a brief description of the models which were given consideration. The models listed range from specific, single purpose models to theater level battlespace simulations. The models listed in Appendix A were studied in particular to determine their applicability to the simulation of naval AAW at NPS. Some of the models listed are no longer available, while others are not yet in service. The higher fidelity models are often limited to one-on-one engagements. These are satisfactory for analysis of a specific aspect of AAW, but they do not offer the versatility of a larger scale simulation. The larger models, though sometimes lacking in detail, often allow the simulation of more of the aspects of AAW. The selection must be made based upon the users' needs, recognizing the fact that one model cannot do all things for all users.

3. Computer Systems at NPS

There are a large variety of computer systems at the Naval Postgraduate School. A number of computer laboratories exist that are dispersed throughout the academic buildings. These labs are mostly comprised of desktop personal computers and workstations, such as the Sun *SPARCStations* in the Physics Department Simulation Lab and the Silicon Graphics Incorporated (SGI) *Iris/Indigo* workstations in the Aeronautics and Astronautics Computer Lab. However, mini-mainframes, an AMDAHL mainframe, and a new Cray computer are also in service at NPS. One determining factor in selecting a computer model is that the hardware must be available on which to run the simulation.

4. Choosing the Model

The Extended Air Defense Simulation (EADSIM), developed by Teledyne Brown Engineering (TBE), was selected as the basis for this thesis. This decision was based on the capabilities of the simulation and the available hardware. EADSIM is a Monte Carlo simulation that offers a high level of flexibility at an acceptable level of fidelity. Although EADSIM was not originally designed for Naval AAW modeling and simulation, it can represent employment of the many systems currently in fleet use. Most naval aircraft are also modeled in EADSIM, and others can be created as will be discussed in later portions of this thesis. The most striking feature of EADSIM is the graphical playback. Any scenario run can be played back in two or three dimensions. Two dimensional playback is superimposed over a map of the modeled battlefield. Three dimensional playback shows terrain elevation, altitude changes of aircraft, and TBM flight profiles. This playback capability gives the operator the ability to view the results of any scenario run. The greatest shortcoming of the model, however, is a lack of missile flyout in an anti-air engagement. This problem has been addressed by other EADSIM users and will be discussed later in this thesis.

The U.S. Army Space and Strategic Defense Command (SSDC) supports EADSIM through its Test Bed Product Office. Software management, configuration and control are accomplished with the assistance of the Army Missile Command (MICOM). These organizations are very effective in supporting the program and have enabled the NPS to become a licensed site for the operation of EADSIM. The Test Bed Product Office also sponsors system training, a quarterly newsletter, and the EADSIM User's Group.

E. THESIS GOALS AND ORGANIZATION

The goals of this thesis are to develop develop a capability to simulate naval AAW systems at NPS, to produce AAW and Strike Warfare scenarios for use in AE3705 and AE3251, and to investigate the weapon performance model of the system selected. The thesis is organized as follows. Chapter II gives an overview of the model, EADSIM, as well as some background and historical information. The operation of EADSIM is the topic of Chapter III. Chapter IV is a description of the scenarios developed for this project. This is followed by the execution of these scenarios in Chapter V. Chapter VI looks at an engineering application of the model. A study of the overall effect of weapon system probability of kill (P_K) investigated for a given scenario. Chapter VII examines the future of EADSIM, its continued development, and a comparison is made of EADSIM with ACES/Phoenix, another new air defense model at NPS. The continued use of EADSIM at NPS and the conclusions this thesis are the topic of Chapter VIII.

II. THE EXTENDED AIR DEFENSE SIMULATION

A. EADSIM OVERVIEW

The Extended Air Defense Simulation, or EADSIM, is a theater level, anti-air warfare computer model. It is described in its Executive Summary as:

> ... an effective and powerful tool for evaluating the effectiveness of various Command, Control, Communications and Intelligence (C3I), theater missile defense, and air defense architectures, as well as weapon systems in the full context of an environment of sensors, Command and Control (C2) centers, communications systems, platform dynamics, and weapons performance. It models both Red and Blue forces and is graphics-based, user-oriented, and highly versatile. [Ref. 8:p. vii]

Originally known as C3ISIM, the model was developed as a prototype for the U.S. Army Strategic Defense Command (SDC), now the Space and Strategic Defense Command (SSDC), and the U.S. Army Missile Command (MICOM). The prime contractor, Teledyne Brown Engineering (TBE), was tasked to produce a low-cost, interim analysis model for Extended Air Defense Concepts until the Extended Air Defense Test Bed (EADTB) is developed [Ref. 8:p. 1-1].

1. Model Description

EADSIM is a unique analytic model of air and missile warfare. Written in *C* computer language and comprising some 300,000 lines of computer code, it separately models each unit (ship, aircraft, missile battery) as well as the interaction between units. Scenarios may be small few-on-few engagements, or large many-on-many battlefield and theater level simulations. These scenarios can be a combination of land, sea, and air battles. A unique feature of EADSIM is that it simulates concurrent Red-on-Blue and

Blue-on-Red encounters. This enables simultaneous active engagements of both sides' offensive and defensive forces to be employed in a single scenario. [Ref. 9]

2. Modeling Capabilities

EADSIM can model a wide variety of offensive and defensive anti-air warfare (AAW) scenarios. Certain aspects of Electronic Warfare (EW) can be modeled, along with numerous aspects of Command, Control, Communications, and Intelligence (C^3I). Terrain is accurately modeled with the use of the Defense Mapping Agency (DMA) data of the world. The DMA library is available on compact disk read only memory (CD-ROM) and can be directly read into a scenario. Table I depicts the general areas modeled by EADSIM as listed in the Executive Summary [Ref. 8:p. 2-1]. EADSIM is not limited to the modeling areas listed in Table I, nor does it perform each of the above functions equally well. Table I does, however, reflect some of the overall capability of the model.

TABLE I - AREAS MODELED WITH EADSIM

Air Defense - Surface-to-Air Missiles -- Antiaircraft -- Antimissile - Command and Control - Air Picture Production and Dissemination Air Operations - Defense Counter-Air - Offensive Counter-Air - Suppression of Enemy Air Defenses (SEAD) - Deep Interdiction Air Bases Surveillance Surface-to-Surface Artillery - Command and Control - Fire Units - Intelligence Gathering and Processing	Generic Noncombatants Communications - Networks - Devices - Individual Messages Electronic Warfare - Jamming of Sensors and Comms - SIGINT Detection in Support of Artillery Terrain - Sensor Masking - Communications Propagation - Flight/Movement Areas of Interest - Track Area of Interest - Missile Engagement Zone (MEZ) - Fighter Engagement Zone (FEZ) - Area of Responsibility - Theater Missile Defense Area (TMDA)

B. HARDWARE REQUIREMENTS

The Extended Air Defense Simulation, in its current form (software Version 2.07), is run on a Silicon Graphics *4-D* Series (or better) workstation. Desirable hardware capabilities for EADSIM include: a 24-bit graphics plane; 64 Megabytes of random access memory (RAM); and 1.2 Gigabytes of hard disk storage space. The 24-bit graphics plane is <u>essential</u> for system operation. It provides a graphics buffering capability for the processing of EADSIM. The software will operate on as little as 8 Megabytes of RAM, however, the scenarios should be small for a lower capacity system and program operation is very slow. Tests have shown that the amount of RAM directly

reflects the system speed and time required for a scenario run [Ref. 10]. Actual hard disk storage requirements also vary based upon user scenario applications. The executable files alone occupy approximately 150 Megabytes of storage. Other recommended hardware includes a personal computer with commercial software applications. Programs such as spreadsheets and plotting routines assist in the manipulation of output data. A printer with a serial interface will complement the system by printing statistics reports for analysis.

As with most computer workstation applications, EADSIM operates under the UNIX operating system. The Silicon Graphics' version of UNIX is known as *IRIX*. Silicon Graphics created *IRIX* for specific use in their computers. Because UNIX has been in use since the late 1960's, it has gone through many revisions. Hence, most workstation manufacturers optimize the operating system for their own hardware. It is noteworthy that most naval tactical decision aids also run under UNIX.

C. SOFTWARE INSTALLATION

The initial installation of the EADSIM software was not easy. The Aeronautics and Astronautics computer lab has three SGI *Iris/Indigo* workstations. Unfortunately, they are not 24-bit graphics capable. Upgrading the computers to the EADSIM system requirements is cost prohibitive. These upgrades would cost twelve thousand dollars per computer, which is more than the original purchase price of each system. Consequently, the Computer Center Visualization Laboratory's (Vis Lab) Silicon Graphics *Power Series 380/VGX* was selected as the host computer for EADSIM. The only shortcoming of the computer initially was a lack of adequate internal hard disk storage. The purchase of a

new 2.1 Gigabyte hard disk for this project proved to be the most cost effective method in which to install EADSIM at NPS. The open source requisition took longer than anticipated. While awaiting the arrival of the new hard disk, the Physics Simulation Laboratory's (Sim Lab) file server was used as the host. Use of the Simulation Lab's file server was accomplished through NPS's NFS (ethernet) network. However, additional difficulties were encountered while loading the EADSIM software into this file server. The Sun Systems *SPARCServer* computer used a different data extract format than that of the EADSIM tape provided by Teledyne Brown Engineering (TBE). Therefore, the software had to be loaded over the network from the Visualization Lab. This process was very slow and took several hours. Other problems encountered with this arrangement was the slow operation of the system after installation. EADSIM utilizes large data files, which do not lend themselves to rapid transmission over a network. Although this was a temporary solution, it was not a very satisfactory solution.

Successful use of the software after it was loaded on the Sim Lab's computer was precluded by corrupted software. The scenarios provided were "seen" by a different version of the EADSIM software. The original tape was run through a computer system at TBE, which had a "Beta" copy of the Version 3.00 code installed. This code is designed to rewrite the older scenarios to the new revised format. Unfortunately, it is an irreversible process, and the original scenario software load was lost. A "Beta" copy of the Version 3.00 code was provided by TBE, but was unworkable. This resulted in a delay of six weeks before a working copy of EADSIM was installed at NPS. Eventually,

a new (uncorrupted) copy of the Version 2.07 software was successfully installed on the new hard disk in the SGI *Power Series 380/VGX* of the Visualization Lab.

D. SYSTEM TRAINING AND SOFTWARE MAINTENANCE

1. Training

To properly maintain EADSIM, it is essential that trained operators be available for user assistance. System training may be contracted through the SSDC project office. Since formal training may not always be feasible, a comprehensive set of instructions is available in the EADSIM User's Manual, User's Reference Manual, Methodology Manual, and Release Notes. The manuals provide sufficient detail for on the job training. Along with the documentation, a telephone support service is maintained by Teledyne Brown Engineering.

The User's Manual describes data preparation, input functions, model operations, and output functions. It has a companion volume, the User's Reference Manual. The User's Reference Manual provides specific descriptions of model functions and window operations of the computer program. The Methodology Manual discusses the modeling approach taken in all aspects of EADSIM. Included in the Methodology Manual is the model architecture, processing logic, timing and sequencing, and key equations.

Hands on training is available from Teledyne Brown Engineering and CAS Incorporated. Support of these training programs is conducted by SSDC. The courses are normally two weeks long, however, tailored lesson programs can be arranged to meet the user's needs. A one week EADSIM user's course to be held at NPS was arranged by

SSDC. A representative from CAS Incorporated presented this course to the author and another NPS student in April 1993.

2. Software Updates

All EADSIM software is government owned. Software updates are conducted through the Change Control Board (CCB) and the Software Configuration Review Board (SCRB). The CCB is a government group, responsible for formal processing of changes to the baseline software. The SCRB reviews the submission of Simulation Change Requests (SCR) forwarded by the users. Should a user develop an enhancement to EADSIM, or discover an error in model operation, that information can be incorporated into the next update of the software. An SCR is filed by any user who requests a change to be made in the model. The SCR's are reviewed by the two boards (SCRB and CCB) for incorporation into the next release of the EADSIM software. Software changes and the content of submitted SCR's are reflected in the Release Notes. [Ref. 11]

An EADSIM User's Group Meeting is held several times per year to discuss model uses, new findings and applications, and to resolve any problems encountered with the model. Major software updates are released to coincide with a User's Group Meeting to ensure maximum dissemination of new material contained in the release. The author attended the last conference in February 1993 at TBE in Huntsville, AL. Refer to Appendix B for lessons learned from the last User's Group Meeting. The next User's Group Meeting is scheduled for 22 - 24 June 1993.

III. EADSIM MODELING AND SYSTEM OPERATION

A. MODELING CAPABILITIES

1. Forces Modeled

Both friendly and hostile forces may be defined in the EADSIM as a variety of platforms. A platform contains sensors, weapons, and communications equipment. Examples of platforms are air breathers (such as aircraft and cruise missiles), ballistic missiles, surface combatants, air bases, surface-to-air missile (SAM) batteries, radar sites, and C^3I nodes. The platforms and associated systems are selected from the data base of the EADSIM library. Their characteristics may be classified up to the secret level. In this thesis, however, the unclassified data base was used. The platform and system libraries may be accessed by the user during scenario generation. Scenario Generation is a utility within EADSIM, which allows the creation (or modification) of a scenario. During scenario generation, the platforms are selected and edited if necessary. These platforms are then added to the battlefield map as part of a laydown file. All of these platforms are displayed as icons within the graphical environment of EADSIM. Targets, also represented as icons, may be any air contact or surface track. The operation of each platform within the simulation is governed by rule sets. The rule sets are defined in the simulation by the type of platform which is modeled. For example, fighter aircraft are modeled using the fighter rule sets to perform offensive maneuvers against hostile air contacts. Rule sets will be discussed in greater detail later in this chapter.

2. Run-Time Processes

The actual modeling of the interaction between the different platforms is accomplished within EADSIM by four parallel run-time processes. They are Detection, C^3I, Propagation, and Flight Processing. Each of these processes performs specific tasks within the simulation to enable the platforms to perform their various missions.

a. Detection Modeling

The Detection process determines the detections made by each platform. Target detection is only accomplished using the free space radar range equation within the EADSIM code. Infrared (IR) detection is not modeled in the current version of EADSIM. Factors incorporated into the model include radar horizon (4/3 Earth model), transmitter power, receiver signal to noise ratio (SNR), radar cross section (RCS), wavelength (λ), minimum detectable signal (MDS), and antenna gain. These factors are normally entered in terms of dBW, rather than their physical values.

The Detection Processor module is a deterministic model used for air targets. The range determined for a target of a given RCS with no jamming present. If jamming were present, then a reduced detection range based on burn-through would result. Radar range can be displayed as a detection envelope superimposed over the scenario map. The radar intervisibility utility develops the display, accounting for terrain and altitude. Detection of ground targets is a statistical model with a random number draw. The detections are then sent to the C^3I Processor. [Ref. 12]

b. C^3I Modeling

The C^3I Processor determines individual platform actions, resolves engagements, processes internal command and track messages, exports movement commands to the Flight Processor, and exports search information back to the Detection Processor. The C^3I Processor conducts all internal message generation, network routing, network loading and message processing. All internal communications are accomplished in this manner. Target tracking, also a C^3I Processor function, is implicit. Tracking is accomplished via truth data, which is the actual location of the target within the simulation. The truth data for a track is continuously maintained by the C^3I Processesor. Once a target is deteced, it is automatically tracked by the detecting radar system based upon truth data from the C^3I Processor. Contact is lost when a target flies out of range, below the horizon, behind a land mass, or is shot down. Operator delays can be programmed into a simulation by increasing reaction time within the model. Target identification is also accomplished within the C^3I Processor module. Mode 4 IFF (identification friend or foe) can be modeled with a simple probabilistic simulation. A random number draw is made when a track is initially acquired. The draw is then compared to the pre-set IFF value, which determines if the target is positively identified as a friendly or hostile. The identification is then permanently assigned to the track. This method is used to represent IFF system reliability, as no IFF system is always accurate. In simple scenarios, IFF may be omitted. When IFF is not used, truth data is used within the scenario to prevent fratricide (Blue-on-Blue engagements). [Ref. 12]

c. Propagation Modeling

External communications are governed by the Propagation Processor of EADSIM. The Propagation Process is used to determine communications connectivity. The connectivity of radio communications is governed by terrain, power, jamming, and atmospherics. In addition, antenna orientation may effect radio communications within the simulation. Connectivity results are exported to the C^3I processor. Connectivity pairing lines may be viewed during scenario generation. These lines display the communications network laydown. Multiple networks may be displayed to show the relationships between the different echelons of command. Control of assets is also shown in this manner. [Ref. 12]

d. Flight Processing

Actual platform movement is performed by the Flight Processing module. It moves platforms according to commands received from the C^3I Processor. It also exports current platform positions, as truth data, to all of the other processors. Aircraft flight within EADSIM uses a three degree of freedom flight model. This model is not an energy model and does not accurately reflect the physics of flight. It does, however, have the capability to have aircraft perform evasive and other tactical maneuvers during a simulation. [Ref. 12]

B. ENGAGEMENTS

An engagement within EADSIM is the simulation of a weapon launch against a target and its outcome. However, weapon launch, flyout, and terminal effects are not explicitly modeled. Engagements are a probabilistic function based upon the default value for

probability of kill (P_K) of a weapon against specific targets. This P_K can be modified by the user during Scenario Generation. A killed target is immediately removed from the simulation run. A missed target will continue to be engaged provided that it still meets target criteria. Most targets cannot be simulated to receive damage. The exception is an air base. If an air base is hit, then a variety of restrictions may be placed on its operation. These include a delay in the aircraft launch schedule to simulate shock, damage, and confused (slower) base personnel.

1. Engagement Pairings

Engagement pairings are graphically displayed in the playback files. Engagement pairing lines on the computer display indicate an engagement against a target. The actual pairing lines change color as an engagement takes place. During the vector phase of a fighter intercept, a purple line appears when the fighter is positioning itself for a shot. The line changes to blue as acquisition and radar lock are made. A white line indicates a weapon in flight. On some playback files, the background or map color interferes with the visibility of pairing lines. If this happens, the color editor can be used to improve visibility of pairing lines.

2. Weapon Performance

Weapon performance is the weak link in EADSIM operation. A major limitation of EADSIM is that it does not model weapon fly-out for anti-air weapons. As such, weapon performance is based upon factors predetermined by EADSIM. These default parameters can be changed by the user during scenario generation. Flight characteristics, such as maximum and minimum range may be set, as well as altitude limits. Speed, radar

cross section, and P_K are explicitly modeled. Their values are assigned to the weapon during scenario generation. Flyout of air to ground weapons may be modeled using the captive platform rule set. This allows an aircraft to carry a weapon, which is modeled separately as an airframe with a warhead. Antiship missiles are frequently modeled in this manner and can be given waypoints to add grin order that they may be viewed during playback.

Re-engagement of missed targets are a function of engageability. Ground targets are attacked with only one pass of the attacking aircraft. If the aircraft gets within weapon release range, then a hit or miss is a function of a P_K draw. Multiple passes may be modeled by programming additional waypoints back to the target. Engagements of air targets continue if the first salvo misses. A firing unit will continue to shoot provided that there is ammunition remaining, the target is still within range and it meets threat criteria.

3. Ammunition and Fuel Expenditure

Ammunition expenditure will continue provided that valid targets remain. Should a unit run out of ammunition, it will begin a reload cycle. For aircraft, they have to land at home base to rearm. An aircraft will also return to base should it reach its fuel reserves. Ammunition expenditure is controlled by the salvo rate for a particular launcher as determined during Scenario Generation. The number of "ready service" rounds are also pre-selected, as is the number of reloads. Reload time is also predetermined during Scenario Generation. During the execution of the scenario, the salvo rates and the reload

cycles are timed along with all of the other simulated events. A launcher will not reload until all of its ready service rounds are expended.

Aircraft expend ammunition in accordance to their respective rule set. Fighters and fighter bombers specifically expend air-to-air missiles as a function of air combat. Fighters will continue to engage hostile aircraft as long as there are missiles remaining. A fighter will stay with its wingman if it has weapons available and has an intercept in progress. Attack aircraft and bombers expend their weapons in accordance with their flight plan. Wild Weasel aircraft expend anti-radiation weapons depending on the number of targets of opportunity. Otherwise, the Wild Weasel aircraft continue to orbit awaiting to be queued by sensor emissions.

Fuel consumption by aircraft is not accurately modeled within EADSIM. The fuel depletion curve is linear, regardless of aircraft speed and altitude. This includes aircraft operating in afterburner. In addition, EADSIM models aircraft idling on a runway as not burning fuel. In most cases, an aircraft will run out of ordnance before it runs out of fuel.

4. Attrition of Forces

The forces involved in a scenario conduct offensive and defensive actions as programmed during Scenario Generation. A ship will continue to defend itself until it runs out of weapons, has no more valid targets, or it is sunk. Attacking aircraft will follow programmed flight paths until they deliver ordnance, are forced to dump ordnance and return to base, or are shot down. Aircraft remaining in a SAM envelope too long will be subject to multiple engagements. If a target is hit, it is destroyed and removed from the simulation. Most scenario runs result in many of the aircraft being destroyed.

5. Re-Engagement of Survivors

Survivors of an engagement are automatically re-engaged, provided they are still valid targets. This gives the advantage to the defender, as it will begin to engage the target at its maximum weapon range and will continue to engage as the target closes. In some scenario runs, a missile system may take as many as four shots against a target.

The chances of the target's survival against four missiles are slim. For example, if the P_K for a given missile against a particular threat is 0.7, then the target has only a 0.3 probability of survival, P_S, after one shot. It can be shown that lethality of the air defense increases with the number of weapons that can be fired. Conversely, survivability decreases with the number of subsequent engagements. The relationship between P_S and P_K is; $P_S = (1 - P_K)^n$. Because the current version of EADSIM has constant single shot probabilities of kill (P_{KSS}) for an engagement, simple probability theory may be followed.

C. RULE SETS

The operation of every platform is accomplished through the use of rule sets. These rule sets are designed for different types of units so that they can follow standard tactics or tactical employment. Rule sets consist of phases of operation, message processing and generation functions, and track files. An example of an operational phase is engagement, when a missile is launched at the target. A message may be an order to engage, telling a unit to fire at a specific track. A track file is the location of a target held by a particular unit. This data may be shared over existing command networks within the scenario. The remainder of this Chapter describes the rule sets used extensively in this thesis.

1. Surface-to-air Missiles

A SAM battery may be assigned the Flexible SAM rule set. As such, it may operate autonomously in self defense, or it may be given a vital asset to protect, or it may be assigned as a subordinate to another unit. As a subordinate, another unit may direct the firing of the SAM battery against a threat. A SAM battery may also be assigned the SAM Commander rule set. The SAM Commander may also have other batteries under its control in addition to its organic capability. Self defense of a SAM battery is accomplished with the use of threatening and critical radii. If a target crosses the threatening radius of a SAM battery, it will be engaged if its closest point of approach falls inside the critical radius. Contacts inside the critical radius are immediately scheduled for engagement. For SAM batteries protecting a vital asset, similar distinctions are made. In this case, the SAM engages the targets threatening the vital asset.

The Flexible Commander is a command unit given authority over other engagement platforms. The flexible commander may have a number of assets under its control. They can be SAM batteries and defensive aircraft. A Flexible Commander may also have other commanders under its control. Entire echelons of a command structure may be modeled in this manner.

2. Defensive Aircraft

a. Fighter Rule Set

Aircraft operating in the role of defensive counter air are assigned the Fighter rule set. Fighters assigned as defensive air will most likely be designated as Combat Air Patrol (CAP). The fighter and its wingman are given a CAP station and waypoints about

which they fly a racetrack pattern. The racetrack can be oriented so that the fighters' sensors are pointed toward the threat axis. Fighters can be ground launched from an air base using a scripted take-off. An air base may also scramble fighters to fill CAP stations which have had their fighters vectored off.

Fighters designated as Interceptors can be scripted to engage a specific target already in flight. The danger of a scripted engagement is that the fighter becomes less useful than a CAP if its initial target is shot down prematurely. The interceptor fighter does not assume an active CAP role, it merely loiters until a target of opportunity presents itself.

b. Fighter Control

Fighter control can be modeled with two methods. One method of control is the Ground Controlled Interceptor (GCI) via the Flexible Commander rule set. The GCI is controlled by a ground station that also has a surveillance radar. The surveillance radar has better range than a fighter's sensors. The second fighter control method is the AWACS (Airborne Early Warning and Control System) rule set. The AWACS has the advantage of being at altitude and is not horizon limited as is the ground radar. Also modeled in EADSIM are AWACS with the Joint Tactical Information Distribution System (JTIDS). With JTIDS, the AWACS can rapidly send orders to fighters under its control without the use of voice commands. This results in an improved reaction time for the AWACS controlled fighters, possibly engaging their target, or targets, before they are counter-detected.

3. Offensive Aircraft

Offensive aircraft follow rule sets strictly according to their mission. EADSIM is principally oriented toward defensive measures, therefore, the offensive rule sets tend to have lower fidelity as compared to the defensive rule sets. These rule sets are designed to perform mainly scripted tasks and do not model command and control functions.

a. Bomber Rule Set

The most basic of the offensive aircraft follow the Bomber rule set. Bombers are strictly air to surface and fly a pre-planned flight path to the ground target. If engaged, bombers will perform evasive maneuvers, employ countermeasures, and resume their mission if the engagement is survived. The bomber rule set does not simulate a pop up or loft deliver of gravity bombs. This may be simulated by scripting the pop up maneuver in the bomber flight path. The model will drop only one bomb on a target during a simulated bombing run. This is an EADSIM limitation. To emulate a multiple bomb release, the P_k of the bomb being delivered is raised. This will have the same effect within the scenario as a multiple bomb release. Bombers cannot be assigned as wingmen, but can fly in formation with a designated flight leader.

b. Fighter-Bomber Rule Set

The Fighter-Bomber rule set is designed to simulate attack aircraft that have a self defense capability. They follow the bomber rule set while on a ground attack mission. If engaged by hostile fighters, fighter-bombers can perform a react to engage maneuver. This may include jettisoning of weapons (a pre-programmed option) and a turn to engage the attacker. The aircraft return to their flight path after the engagement

is resolved, or return to base if all air-to-surface weapons were jettisoned. The fighter-bomber may not be assigned as a wingman for combat support, but may also fly in formation with a flight leader.

c. Escort Fighter Rule Set

Escort Fighters are fully reactive in air combat. They may be assigned as wingmen to bombers and fighter-bombers. This allows them to be employed as protection for the aircraft performing an attack mission. Phases of operation are similar to those of the fighter rule set without a target selection phase. The escort fighter becomes active in air combat if it, or the aircraft it is assigned to protect, is attacked. If such an attack occurs, the escort fighter performs the "react to engagement maneuvers" of a fighter-bomber.

d. Fighter Sweep Rule Set

Fighter sweeps are accomplished with the "Sweeper" rule set. It follows logic identical to the fighter rule set, except that there is no message processing capability. As a result, the sweeper cannot receive AWACS or GCI radar data. This can result in multiple fighter sweeps attacking the same target. Sweepers also cannot be assigned wingmen, thus they only operate in single flights. Such operation may cause a bias in scenario results. Experienced EADSIM users have discovered that smaller flights often outperform larger flights of aircraft. This problem is inherent to the logic of the program, which allows small formations of aircraft to fly more aggressively than large formations. Thus, the use of the Sweeper rule set is not recommended. [Ref. 12]

e. Wild Weasel Rule Set

The Wild Weasel rule set offers the highest fidelity of any offensive aircraft. The rule set is semi-scripted, in that the Wild Weasel is given a potential list of targets, and it dynamically selects a target if its emitter is detected on the battlefield. If the received signal is above the launch threshold, it closes to weapon release range. If already in range, the Wild Weasel performs "avoid lock" and triangulation maneuvers. An anti-radiation weapon is then fired if launch conditions are met. Following launch, the aircraft returns to its programmed flight path or operating station. A Wild Weasel will continue to attack ground radars on its target list provided it receives emissions and it has anti-radiation weapons remaining.

If attacked by hostile fighters, the Wild Weasel performs maneuvers identical to those of the fighter-bomber. The Wild Weasel aircraft also maneuvers aggressively in reaction to lock-on if engaged by a SAM. This improves the survivability of the aircraft and closely models real world maneuvers. Operator modifications to the Wild Weasel rule set may be selected from a menu of options. These are designed to improve the fidelity of employment of SEAD aircraft. Thresholds can be varied to reouire the wild weasel to be painted more (or fewer) times to react. In addition, reaction maneuvers can also be modified.

4. Rule Set Modification

Rule sets can be modified to achieve higher levels of fidelity. By assigning multiple rule sets, a platform can be given enhanced capabilities. One such example is to designate a CAP flight leader as a flexible commander as well. This will give it more

autonomy in employing its wingman. Other rule set modifications can be made at the source code level. The *Lockheed* Corporation has created an improved fighter-bomber rule set (called *Ghostrider*) to emulate a proposed capability of the A/F-X. With this model, the aircraft performs equally well in either fighter or attack mode. It may also switch from one mode to another as the situation within the scenario changes. Source code modifications are beyond the scope of this project and will not be attempted.

5. Areas of Interest

For any scenario, a certain readiness posture is implicitly modeled. EADSIM assumes that "hot war" conditions exist. Should a target be determined to be a threat, it will be engaged. Rules of engagement (ROE) may be explicitly modeled with areas of interest (AOI). The AOI rule set models missile engagement zones (MEZ) and fighter engagement zones (FEZ). Friendly aircraft can be given safety routes through an AOI to prevent fratricide.

IV. SCENARIOS DEVELOPED FOR NPS

A. SCENARIO REQUIREMENTS

1. Modeling of Navy Assets

EADSIM has only a limited selection of warships and naval aircraft pre-built in the platform and system libraries. This is mainly a result of EADSIM's origin as an Army project. Much of the modeling of the air combat represented by EADSIM was developed with the aid of Air Force pilots. Thus, there has been less Navy support for the simulation as compared to the other services. Although not originally designed to do so, surface ships and carrier based aircraft can be represented within the simulation. This is enabled by modifying the existing rule sets previously discussed in Chapter III. With manipulation of the rule sets, many naval units can be created with an acceptable degree of fidelity.

The simulation of naval units can be accomplished by one of two methods. The first, and simplest, method is to modify an existing system. The specifications of systems in the EADSIM library may be modified to reflect those desired by the user. Care must be taken by the user to ensure that "generic" numbers are used, so as not to risk accidental disclosure of classified data. A common practice is to use specifications given in *Jane's* or other such open sources of information. In addition, the user should give the "new" unit a name other than the default designation. This will prevent overwriting the default values for the original system.

The second manner in which to create a unit is to build the systems from scratch. This is done within the existing rule sets of EADSIM. For example, the F/A-18, which is not modeled in EADSIM, may be represented by following the fighter-bomber rule set in the unclassified database. All the aircraft characteristics are entered into EADSIM during scenario generation. Again the specifications of the actual system are represented within the model, as programmed by the user.

B. THE AAW SIMULATION FOR USE IN AE3705

1. Naval Forces Operating in Littoral Waters

A new mission statement for the United States Navy describes Naval and Marine Corps units "operating forward from the sea [Ref. 5]." As such, Naval conflicts in the future are less likely to be conducted on the open ocean and more likely to occur in coastal or littoral waters. The anti-air warfare simulation modeled in this thesis consists of naval forces operating in littoral waters. Three scenerios are developed. One scenario investigates the AAW self-defense capability of a ship operating alone in Eastern Mediterranean waters. A second scenario has two ships operating together against the same threat. Two runs of the two ship scenarios are to be conducted in the lab, to explore the EADSIM modeling of command networks. One run is conducted with the ships operating autonomously. A second run has the ships under a centralized command. In the latter case, one ship directs the engagement of hostile air contacts for both vessels. The final AAW scenario concerns the defense of a vital asset. The ships from the previous scenario are assigned to protect an aircraft carrier against the same air threat. A comparison of centralized control (carrier vs. cruiser) is studied with this scenario.

Because the primary area of interest is surface ship AAW, the carrier air wing is purposely left out of the scenario. Thus, combat air patrol (CAP) and other fighters are not available.

2. The Threat

The threats selected are from a hostile Middle Eastern nation. They consist of "Red" manned aircraft and anti-ship cruise missiles (ASCM's). The ASCM threat are both shore launched and air launched. The shore launched anti-ship missiles are an approximation of the *Silkworm* missile. The *Silkworm* is itself a modification of a first generation ASCM, the SS-2-N *Styx*. The *Styx* was the first weapon of its type to be successfully used in combat. It is credited with the sinking of the Israeli destroyer *Eliath* during the 1967 Six Day War. Although *Styx* is approaching obsolescence, its Chinese built successor has seen much use in the Persian Gulf Wars of the past decade. Because of the open source data available on *Silkworm* and because it is a likely threat, it was selected for this scenario. Modeling of a shore launched ASCM uses the TEL icon. The weapon on the TEL is given the flight profile of a typical ASCM.

Air launched versions of *Silkworm* can be carried by the Tu-16 *Badger* bomber. The modeling of an air launched missile is more complex because it must be modeled as a captive platform. This is accomplished by creating an airframe carrying a separate warhead. By doing so, the hybrid weapon can be given its own flight path when fired from its launch platform. The addition of the long range air threat is designed to create multiple threat axes and to possibly saturate the defending ship's air defense.

Other attacking aircraft are the MiG-23 *Flogger*, which follow the fighter bomber rule set. They are armed with gravity bombs and standoff weapons. The standoff weapons of a fighter-bomber are not modeled as a captured platform. As such, there is no specific weapon flyout, only a P_k against the target. The *Floggers* are programmed to fly varying low level ingress routes to their naval targets. As with *Silkworm*, the MiG-23 is an aircraft common to many potential adversaries and was thus selected for this project. To further complicate air defense measures, the attacking Red forces are scripted to conduct a coordinated attack against the Blue units.

3. Ships Operating Autonomously

The first group of scenario runs are concerned with ships operating alone. The surface ships modeled in the AAW scenarios are "Blue" units. Specifically, they are an Aegis cruiser and a *Spruance* Class Destroyer operating in the Eastern Mediterranean. The cruiser is equipped with the AN/SPY-1 phased array radar and the SM-2 naval SAM. These systems are modified from the elements available within EADSIM. Unclassified parameters of the SPY-1 radar replace those of the Patriot AN/MPQ-53 phased array. This sensor is then installed on the Aegis cruiser icon within the scenario. The SM-2 modeled is a modification of the *Standard* missile found in the simulation library. The destroyer is equipped with the NATO Sea Sparrow missile system. This weapon system is also an adaptation of those existing within EADSIM. The modifications are conducted to more closely model the missile specifications as found in *Jane's* and other unclassified sources.

4. Ships Operating Together

In the second set of scenario runs, the two units mentioned above operate together. One run has the ships operating under independent command. The second run has the ships operating under a combined command structure. This allows the simulation of a real world command and control structure, such as the Naval Tactical Data System (NTDS). It also should eliminate dual engagement of a target by both ships and ensure the protection of destroyer by the area defense capability of the cruiser.

5. Protection of a High Value Unit

The final version of the of scenario concerns the protection of a vital asset. In this case, the high value unit is an aircraft carrier (CV). The two ships, as modeled above, are positioned to protect the CV. The destroyer, with the short range AAW weapons is positioned close to the CV and the cruiser, with its longer range missiles, is positioned up the threat axis. Two versions of this scenario are to be conducted, one with command and control on the carrier, the other with C^3I on the cruiser. The purpose of this exercise is to determine if the command authority has any effect on the scenario outcome. In both cases, the CV is defined as a vital asset.

6. Other Variations

The scenarios are designed to determine any advantages of an area defense system, such as Aegis over the point defense systems of a less capable surface combatant. In addition, ship positioning against a threat can also be studied. The student in AE3705 may want to vary weapon parameters such as range and probability of kill Furthermore,

the command networks may be analyzed by the student. The C^3I functions of a tactical data link are critical to fleet operations.

C. THE AIRCRAFT STRIKE SIMULATION FOR USE IN AE3251

1. Aircraft Strike Against a Defended Target

The air assets conducting the strike are Blue. The attack aircraft is the F/A-18 Hornet and the jamming aircraft is the EA-6B *Prowler*, neither of which are in the standard EADSIM library. The F/A-18 is created using the Fighter Bomber rule set, and the EA-6B is created using the Wild Weasel rule set and other systems within EADSIM. A-6E *Intruders* may also be modeled with the Wild Weasel rule set so that they may carry anti-radiation missiles (ARM's). The Blue fighter aircraft covering the strike package in one phase of this scenario is the F-14 *Tomcat*. The F-14 is contained in the EADSIM library.

The ground units that are being attacked are generic airfields near Beirut. They are defended by a variety of Red SAM's and early warning radar. The basis of this scenario was provided by Teledyne Brown Engineering. It has been used by TBE in the demonstration of EADSIM to potential users. The original scenario uses Air Force units with AWACS support against a similar air defense arount Baghdad.

The defensive counter air consists of Red MiG-29 *Fulcrums* and Red MiG-25 *Foxbat* fighters. The defensive aircraft are placed on CAP stations above their air bases. They may be directed by GCI stations, but do they not have airborne early warning support. Additional ground launched interceptors are left out of the scenario for simplicity.

2. Unprotected Raid

The simulation of strike aircraft attacking defended ground targets is accomplished in five phases. The first phase has attack aircraft conducting a strike against enemy airfields defended by surface-to-air missiles (SAM's). Flights of F/A-18 aircraft attack two airfields heavily defended by SAM's. The strike aircraft are unprotected and armed with only gravity bombs. This is a worst case scenario. It will show that an unprotected attack against an integrated air defense network is difficult.

3. Adding Stand-Off Weapons

A second phase of this particular scenario gives the attackers stand-off weapons, in the hope to avoid the air defense. The *Maverick* missiles should minimize the strike's exposure to the hostile SAM envelopes.

4. Suppression of Enemy Air Defense

The third phase further improves the survivability of the strike aircraft by arming some of the them with anti-radiation missiles. In this version of the strike scenario, the attack aircraft may still be exposed to the Defending SAM batteries. To protect the strike package, stand-off jamming and the Wild Weasel rule set are used to degrade radar sensors and actively employ anti-radiation missiles against the SAM sites. As a result, the aircraft attacking the ground targets in this third phase, are less susceptible to ground fire. The modeling of countermeasures against anti-air weapons has the effect of "anti-weapons". EADSIM lowers the P_K of the weapon in the presence of countermeasures.

5. Defensive Counter Air

Defensive counter air opposes the strike in the fourth phase. The scenario now has CAP and ground launched interceptors available to the defender. They are MiG-29 *Fulcrum* and F-1 *Mirage* fighters, which are comparable to the F/A-18 in air-to-air combat. The MiG and *Mirage* fighters will have the support of ground control intercept (GCI) radar and have the advantage of not carrying the extra weight of ordnance as do their opponents. The F/A-18's will be following the fighter-bomber rule set and may jettison their ordnance to engage the hostile fighters. Fighter aircraft on combat air patrol (CAP) stations are positioned to defend their base. They can be directed by ground radar, or rely on their own sensors. The defensive counter aircraft follow the Ground Controlled Interceptor (GCI) fighter rule set.

6. Escort Fighters

To defend the attack aircraft, a fighter escort is incorporated into the fifth phase. The escort is the F-14A *Tomcat* and will accompany the strike package along the mission route. The escorts can be modeled with the Escort Fighter rule set, or conduct fighter sweeps using the Sweeper rule set. In either case, the escorts engage the defending CAP, allowing the strike aircraft to perform their mission.

Because of the capability of EADSIM, a far more complex air battle may be modeled. The use of early warning aircraft, such as AWACS, can greatly improve the effectiveness of one side's fighters. The defender can also be given an advantage by allowing numerous ground sensors and a more sophisticated C^3 network. Another EADSIM limitation is encountered in these air-to-air engagement scenarios. There is not

an exact modeling of the AWG-9 or other multiple engagement radar system. Simultaneous engagement with multiple *Phoenix*, or other extended range air-to-air missiles AAM's, is not modeled within EADSIM.

7. Other Variations

These Strike Warfare scenarios are specifically designed for AE3251. They are created to show the effect of different measures and countermeasures that may be employed to increase the survivability of a strike aircraft. A parameter students may investigate is the reduction of radar cross section (RCS). By reducing RCS, students may see a direct correlation with increased survivability.

D. SCENARIO GUIDE AND USER'S GUIDE

An EADSIM Scenario Guide (Appendix C) and User's Guide (Appendix D) have been developed for laboratory use. Should EADSIM be programmed into either AE3705 "Air Defense Lethality" or AE3251 "Aircraft Combat Survivability," the guides will assist the uninitiated student through a scenario. The Scenario Guide contains the descriptions of this chapter, the available assets of both Red and Blue, and their employment within the scenario. The scenarios are scripted so that students need not create their own.

Because of the complexity of EADSIM and the UNIX operating system (most students cannot be expected to have sufficient UNIX experience), the User's Guided is a programmed text that takes the student through the scenario playback function step by step. This will allow a student to view a playback file with little system experience. Should a student desire more knowledge of EADSIM, the reference manuals are available in the laboratory.

V. SCENARIO EXECUTION

A. RUN-TIME SIMULATION

The actual execution of an EADSIM scenario is conducted in "real time" with respect to the platforms involved. The Scenario Execution routine starts the four run-time models of Detection, C^3I, Propagation, and Flight Processing that were discussed in Chapter III. The four run-time models are separated using the multiple processor architecture of the Visualization Lab's Silicon Graphics *380/VGX*. Each is model is processed on its own CPU within the computer. This division of the processing is similar to dividing the processes over several desktop workstations. By using the power and memory of the *380/VGX*, the user is able to perform several scenario runs in the time that it would take for a single run on a lesser machine. The Scenario Execution routine also determines if the scenario run had a successful start. It allows for final scenario editing, specification of output files, and setting of Monte Carlo options.

B. MONTE CARLO RUNS

The Monte Carlo options are accessed within the program from the Scenario Execution routine. Monte Carlo runs may be conducted in two ways. In the first, the user selects the random number seed for each scenario run. The second method allows the computer to select the next random number for each consecutive run. EADSIM executes the scenario for the specified number of Monte Carlo runs selected by the user. Each run is saved in its own file, designated by a number tacked on to the file name. The

results of each Monte Carlo run are different, although at first appearance they may look similar.

In the Monte Carlo method, a different random number seed may be used for each run. A UNIX workstation with software programmed in *C* can produce over two billion random numbers. Specifically, $2 * 10^{31} - 1$ numbers can be generated by the following subroutine written in *C*:

```
max = pow(2.0, 31.0)-1.0;
scanf("%d", &seed);
srandom(seed);
r = random()/max;
```

The random number generator may be modified so that it can produce multiple random numbers for many Monte Carlo runs of a large scenario.

C. COMPUTER GENERATED REPORTS

The Post Processing routine of EADSIM is the primary method of generating statistical reports concerning the results of a scenario run. The user can define the reports prior to scenario run or during Scenario Generation. All platform activity in a scenario run may be reported, or specific actions for specific platforms can be reported. These reports are formatted as text files that can be printed or downloaded into an off-line application such as a spreadsheet. Post Processing occurs after the run-time processes have been executed. There are two basic report types, history and time interval. A history report gives the data in the order that it occurred. A time interval report gives

data in the same order as the history report, but only during the specific time interval as set by the user. [Ref. 13:p. 9-1]

1. Detection Post Processing Reports

The Detection Statistics reports provide a record of detections made during a scenario run. A variety of specifications may be selected by the user. These include Total Detections, First Detections, Detected By, Detected From, and Time Interval [Ref. 13:p. 9-1]. First Detections can be further optimized to give those of a particular sensor or platform and may also give the range, altitude, azimuth and elevation angle of the detection [Ref. 13:p. 9-1]. These options allow the user to analyze the performance of a particular sensor or platform.

2. Communications Post Processing Reports

The Communications statistics reports provide a record of message traffic sent over the command networks of an EADSIM scenario [Ref. 13:p. 9-1]. They can be used to report on all of the networks of a scenario, or only those networks selected by the user. The user may use the reports to analyze the effectiveness of the communications networks of the scenario.

3. Engagement Post Processor

The Engagement statistics report provides a record of engagements taken against one platform by another. The user may select all engagement actions, or specific engagement actions such as air-to-air engagements. The user may also select engagement actions performed by specific platforms. This will allow the user to isolate the performance of that particular platform. [Ref. 13:p. 9-1]

E. DATA

The data for the two scenarios run as part of this project are contained in the Post Processing reports. The reports are generated at the time of the scenario run and stored by the computer. They can be printed off-line for future analysis, or downloaded into an off-line application. Each report can run several hundred pages and contains a description of scenario events. The same data is used in the playback file. Refer to Appendix E for an excerpt from the Post Processing report of the Naval AAW scenario.

F. SCENARIO PLAYBACK

One of the easiest ways to observe the results of a particular scenario run is to simply view the scenario playback file. EADSIM provides a Playback routine that is selected through the graphical user interface. A playback file is based upon truth data provided by the run-time processes. A playback shows a visual representation of the simulation superimposed over the battlefield map. The individual icons of the platforms move in accordance with their operation within the scenario. By observing the playback, the user can observe the timing of certain events, such as initial detection, when a ship or missile battery begins to fire, or when a fighter begins an intercept. The playback file displays the engagement pairing lines. These lines indicate which of the firing units are engaging specific targets. If a target is destroyed, then a symbol is left on the map to indicate where it was destroyed. A circle with a slash through it indicates a downed aircraft, a square with a slash through it indicates a destroyed surface target, or ship. Missiles that are destroyed are not indicated by a symbol.

VI. EFFECT OF CHANGING PROBABILITY OF KILL

A. THE EADSIM WEAPON MODEL

1. Probability of Kill

Because weapon modeling is considered to be a weakness of EADSIM, the author has investigated a specific aspect of the weapon model, the probability of kill (P_K) for surface-to-air missiles. The P_K values found in the EADSIM library are default values for the particular weapon being modeled. The P_K of a weapon in EADSIM is in reality a single shot probability of kill, P_{KSS}. Because the engagement function of an EADSIM scenario has been reduced to a kill or survive determination, the term P_K is used.

2. User Selectable P_K

Some weapons in the model may not have a default P_K intentionally, or the user may desire to change a default value. Should the user create a new weapon within the model, then a user selected default P_K would also be programmed. Furthermore, individual P_K values may be programmed by the user for a weapon against several types of targets [Ref. 13:p. 4-4]. For example, the user might give P_K of 0.85 against a MiG-27, but the same missile may be given a P_K of only 0.70 against a MiG-29 in the same scenario.

3. Anti-Weapons

The P_K of a weapon may be affected within a simulation by the employment of chaff or decoys. Such deceptive countermeasures are modeled in EADSIM as "anti-weapons". The presence of an anti-weapon will reduce the P_K of the weapon for that engagement. This is

accomplished by the anti-weapon having a value of its own. For example, an anti-weapon with a value of 0.5 will reduce the P_K of a weapon by 50%.

4. Kill or Survive

With the exception of damage to an airbase, engagements in EADSIM are all-or-nothing events. Therefore, the engagement outcomes are modeled as "kill" or "no-kill" events. A kill or no-kill outcome is determined by a random number draw against the P_K of a weapon. If the P_K is greater than the random number draw, then the engagement is a kill [Ref. 13:p. 4-31]. The coding of a random number generator in *C* is discussed in Chapter V. The comparison of P_K versus the random number (r) can be written in one line of *C*.

```
if (Pk>r) kill=1;
```

The above statement assumes that "kill=1" in the program is a successful engagement.

B. WEAPONS CREATED FOR THIS STUDY

To conduct this lethality study, a series of baseline weapons was created by the author. These "generic" missiles have been generated entirely within EADSIM using hypothetical parameters. This is to avoid any direct correlation with real world systems and to avoid all possible classification restrictions. The generic missiles do, however, correlate with the missions of many missile systems used in the fleet today. To test these weapons, a scenario was generated with one missile ship and one unarmed aircraft to act as a target drone. The ship was also equipped with only one missile for each run to avoid automatic re-engagement if the target was not killed. For experimental consistency, the drone flew a level flight path toward the ship. Altitude of the drone was increased for the longer range missiles so that it

would stay above the ship's radar horizon. No jamming or countermeasures were present, as they would effect sensor and weapon performance.

1. Point Defense SAM

The point defense SAM in this study simulates a typical close-in missile system that may be found on any warship, small combatant, or auxiliary ship. It has a range of five kilometers, or approximately three nautical miles. A point defense missile is used as a last ditch defense against an attack. Point defense systems are considered to be effective only in defense of the ship on which it is installed.

2. Short Range SAM

The short range SAM of this study simulates a typical missile system that may be found on a typical destroyer, frigate, or large auxiliary ship. It has a range of 15 kilometers, or approximately eight nautical miles. A short range missile system offers increased range over point defense systems and has a limited capability against crossing targets. Therefore, a ship equipped with a short range missile can perform escort duties if stationed close to the unit it is assigned to defend.

3. Medium Range SAM

The medium range SAM of this study simulates a typical missile system that may be found on an older guided missile ship and has a range of 50 kilometers, or approximately 27 nautical miles. A medium range missile system provides improved defense over the short range system. It can engage crossing targets at a greater range and escort positioning is not as critical.

4. Long Range SAM

The long range SAM of this study simulates a modern area defense missile that may be found on a guided missile cruiser or large guided missile destroyer. It has a range of 100 kilometers, or approximately 55 nautical miles. A ship equipped with an area defense missile system need not be stationed close to the unit(s) it is assigned to defend. A long range missile provides an air defense umbrella for the ship and other units operating with it.

5. Extended range SAM

The extended range SAM of this study simulates a new generation of area defense missiles. It has a range of 200 kilometers, or approximately 110 nautical miles. The extended range of the missile allows a surface ship to participate in the outer air battle. It also enables surface ships to engage bombers with long range ASCM's beyond their normal weapon release range.

C. RESULTS DUE TO MODIFICATION OF PROBABILITY OF KILL

The weapons modeled for this study were given different probabilities of kill against the same target. Each weapon was given P_K values of 0.50, 0.65, and 0.80 for each set of scenario runs. The five missiles were then individually employed against the target aircraft at the three values of P_K. A total of fifteen sets of scenario runs were conducted in this study, with ten runs being conducted for each set.

1. Monte Carlo Runs

The Monte Carlo options were set for ten runs of each missile, at each value of P_K, to be conducted consecutively. This feature also allows a different random number seed to

be selected for each run. Varying random number seed is critical in such a controlled scenario. Otherwise, the same results will occur for each scenario run.

2. Results

Table II contains the results of the multiple scenario runs for each missile at each P_K. A direct correlation between the probability of kill and the number of targets killed was observed in this study. For the different missiles, range did not have an effect on the simulation results as expected. EADSIM will fire a weapon when the target enters the weapon's lethal range.

TABLE II - RESULTS OF PROBABILITY OF KILL STUDY

Number of kills in 10 attempts

P_K Value	Point Defense SAM	Short Range SAM	Medium Range SAM	Long Range SAM	Extended Range SAM
$P_K = 0.50$	4	3	5	5	6
$P_K = 0.65$	8	5	6	5	6
$P_K = 0.80$	7	8	9	9	9

D. MISSILE LETHALITY ENVELOPES

1. Real World Envelopes

Real world missile systems have lethality envelopes based upon the missile's P_K. They are generally based upon a P_{KSS} value of 0.5, but lethality envelopes for any P_{KSS} can be developed. These envelopes enclose a volume based upon the range, azimuth, and altitude of a target and can be given as missile launch or intercept lethality envelopes. Figure 1 depicts a typical missile lethality envelope based on intercept. [Ref. 2]

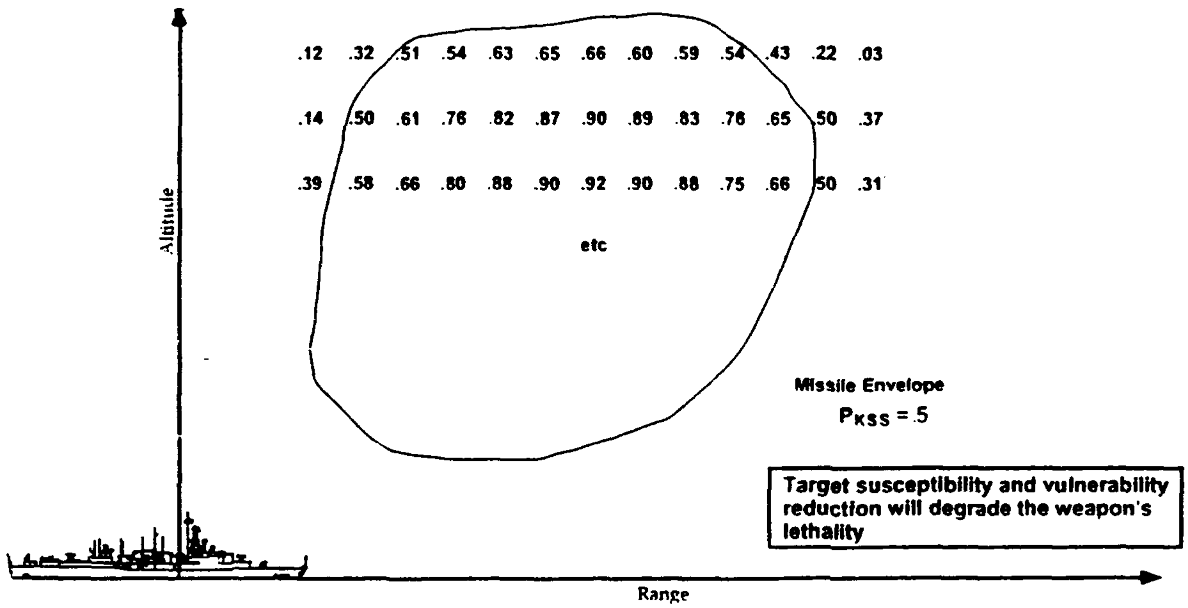

Figure 2 - Typical Missile Lethality Envelope

2. Modifications to P_K Within EADSIM

Because the missile firing doctrine in EADSIM has the system to make the earliest possible intercept, the creation of envelopes using EADSIM data would not be realistic.

These envelopes would be shaped such that the majority of the engagements would be conducted at the outer edges of the missile's lethal range. Figure 2 depicts what an EADSIM missile lethality envelope may look like with engagements made at maximum range.

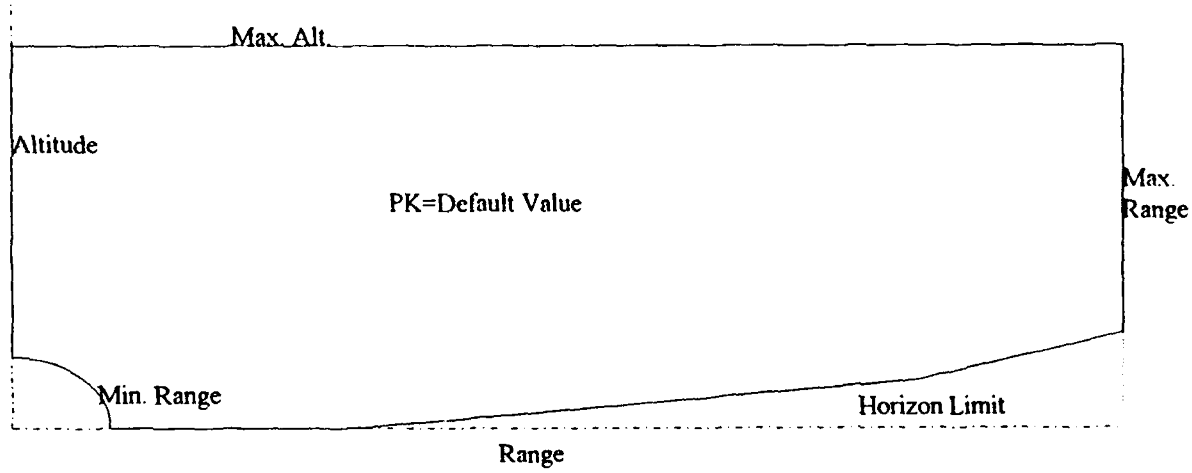

Figure 2 - EADSIM Missile Lethality Envelope

a. P_K Roll-Off

Probability of kill roll-off parameters may be programmed by the user in an attempt to model an engagement envelope. The envelope begins with a user specified P_K and remains constant out to the "Begin Roll-Off" percentage of the lethal range against the target. The P_K then rolls off linearly from the user specified P_K at the selected Begin Roll-Off range to the "End Roll-Off" range. End Roll-Off range is also a percentage of the weapon's lethal range. Probability of kill roll-off is only modeled for the SAM systems. [Ref. 14] Figure 3 depicts what an EADSIM missile lethality envelope would look like with the roll-off feature enabled.

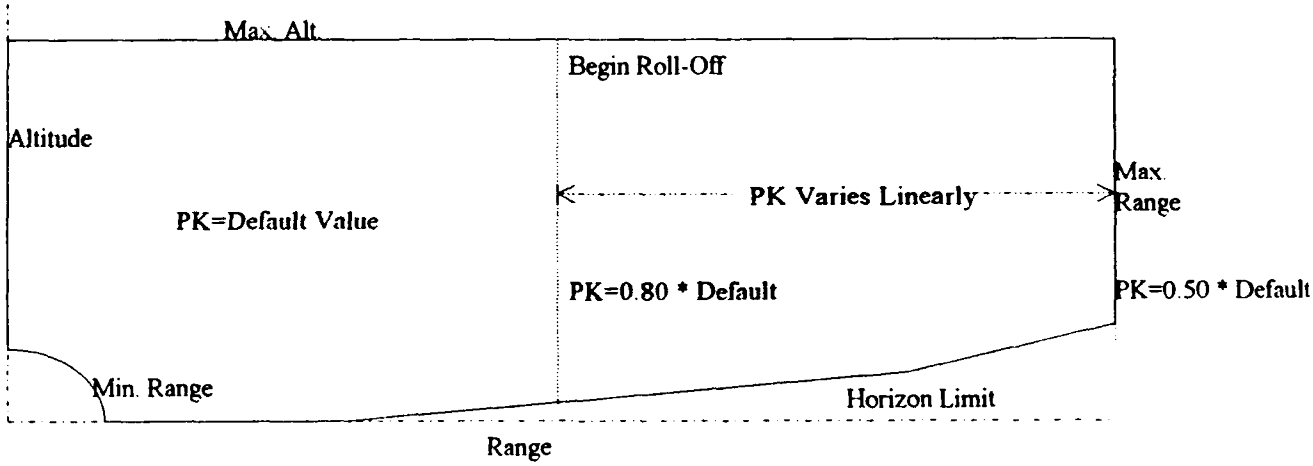

Figure 3 - Missile Lethality Envelope
With P_K Roll-Off Enabled

The author's experience with P_K roll-off within the program indicates that this feature does not work properly. Tests similar to the original P_K study were conducted with the roll-off feature enabled, but did not indicate appreciably different results.

b. P_k Tables

Probability of kill tables could be created to model lethality envelopes. The tables could be a matrix of P_K's based upon the target's range and altitude. Factors such as target velocity and target crossing angle could be modeled in the same manner. User selectable parameters would be a useful option, such as user determined P_K's against different aircraft types. The next release of the EADSIM software, discussed in the coming chapter, will include P_K tables. Figure 4 depicts a real world missile lethality envelope for a medium or long range missile that can be modeled using P_K tables.

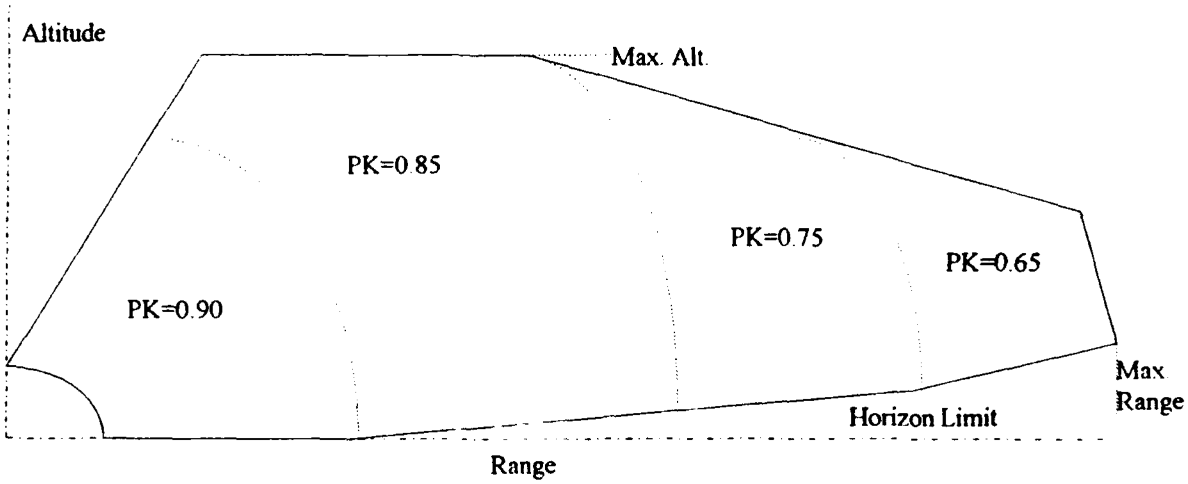

Figure 4 - Real World Missile Lethality Envelope

VII. FUTURE DEVELOPMENT

A. FUTURE GROWTH OF EADSIM

1. EADSIM Version 3.00

The Extended Air Defense Simulation has evolved into a major program since its initial inception. Future growth of the program will continue as long as EADSIM remains an effective air defense model and further upgrades are made to meet the needs of users. The next generation of EADSIM software is Version 3.00 (V3.00), scheduled for release in late June 1993. It will incorporate many of the changes requested by EADSIM users and will offer some enhanced modeling features. Some of the features involved will allow smoother model operation, while others will improve the fidelity of a simulation. Many of the enhancements being incorporated into the new baseline (V3.00) software were presented at the last EADSIM User's Group Meeting [Ref. 15]. Nearly 100 EADSIM users were in attendance. A listing of all organizations currently registered as EADSIM users is contained in Appendix F.

a. Major Enhancements

Among the most important new features with respect to this project, is the addition of P_K tables. This will allow a more realistic outcome of an engagement. The tables will be represented by a multidimensional array of probabilities. Each will represent the P_K for a partiˆular engagement type (e.g., air-to-air, surface-to-air, etc.) based upon a variety of dynamic factors. The parameters include range, altitude, velocity,

azimuth and elevation. User selectable combinations of parameters can be entered prior to a scenario run. By modeling the terminal engagement in this manner, crossing angle limitations, aspect angle, and other geometric considerations can be represented in a simulation. The P_K tables will improve the fidelity of engagements because all engagements are different and not merely a result of a random number draw as currently modeled.

Kill assessment has also been considered a weakness in the modeling process. In its current form, kill assessment is based upon truth data. Therefore, if a target is killed, it is removed from the scenario. Targets remaining alive are automatically assessed as being alive and can be re-engaged. The new kill assessment routine includes error modeling. This enables "dead" targets to be assessed as "alive," resulting in false alarms. Conversely, "alive" targets assessed as "dead" will appear as leakers, or missed targets. The error modeling is based upon preprogrammed false alarm rates and leaker rates as selected by the user. [Ref. 16]

The Aircraft Flight Model within EADSIM has been a simplistic three degree of freedom representation. Currently, EADSIM models only forces that impact on aircraft acceleration, which is not a true force model [Ref. 12]. Near term enhancements will include a constant altitude flight path, replacing the current straight line flight path which does not account for curvature of the earth. Other improvements will allow radius of turn and turn rates for specific aircraft types, user specified formations, F-pole maneuvers, and drag maneuvers [Ref. 16]. Another possibility for future inclusion is a five degree of

freedom energy model that analytically represents the dependency of available thrust on mach and altitude.

Infra-red sensor modeling will be incorporated into EADSIM V3.00. Areas to be represented are target signature, clutter, and path loss. An atmospheric model, LOWTRAN, is used to generate clutter and path loss. Adding an infra-red capability to EADSIM allows the representation of IR sensors and IR missile seekers within the model. [Ref. 16]

The enhanced radar model of V3.00 will account for radar propagation effects in the atmosphere [Ref. 15]. Clutter and noise will reduce radar performance within the model in a manner emulating real world losses. Expanded antenna modeling will allow the modeling of nulls and lobes in a radar antenna pattern. Currently, only the main beam of a radar is modeled. The enhanced radar model greatly improves upon the current modeling of the free space radar range equation as discussed in Chapter III of this thesis. Again, higher fidelity is achieved in another important aspect of AAW simulation.

Other improvements being made to V3.00 include a non-graphical post processor, improved Monte Carlo execution, and a new ballistic missile model. All of these improvements are designed to add to the usefulness of the model and to make the model more user friendly. [Ref. 16]

b. Sun System Compatible

Version 3.00 of the EADSIM software offers new potentials concerning its use. This new version is compatible with the Sun Computer Systems' *SPARCStation 2* series workstations, as well as the SGI workstations in which EADSIM currently runs. Previous

releases could only run on Silicon Graphics workstations. A reduced icon set is used for the Sun to speed model operation. Graphics accelerator boards may also be installed into a Sun workstation to improve system performance. The numerical results when run on a Sun, however, are nearly identical to SGI results. Test have shown a variance of less than one per cent in simulation results [Ref. 16]. The software installation is the same for both types of computer systems. The differences in the load subroutines are transparent to the operator. While the software is being loaded, it recognizes the operating system of the host computer workstation in which it is being installed.

c. Integration of Site Modifications

Much of the work involved with the previous improvements has been done at sites other than Teledyne Brown Engineering. Other organizations have conducted source code modifications to EADSIM and have requested that their modifications become part of the EADSIM baseline. The procedure for submitting the Software Change Requests is discussed in Chapter II of this thesis. Once approved, the software improvements are scheduled for integration into a subsequent release of an EADSIM baseline.

Some of the major contributions to EADSIM V3.00 by other organizations are given below. They are being integrated into the baseline by TBE. Lockheed is responsible for the infra-red sensor capability incorporated into V3.00 [Ref. 16]. Lockheed has also written new procedures for aircraft reaction to a SAM threat [Ref. 17]. Raytheon has assisted with the development of the P_K tables [Ref. 16]. CAS Incorporated and the SHAPE Technical Center are responsible for display improvements and improved methods in which to edit a platform [Ref. 18]. JADO/JEZ has done work in numerous

areas including improved fighter tactics and multiple simultaneous aircraft engagements [Ref. 19]. The Center for Naval Analysis has introduced new fighter vectoring procedures for EADSIM [Ref. 20].

2. EADSIM Version 4.00

Because EADSIM is continually receiving improvements, new releases of the software come out several times each year. The next major release of EADSIM following V3.00 will be Version 4.00, which is already under development. The proposed release date for V4.00 is scheduled for December 1993. This new release will include some improvements that were originally slated for V3.00, but could not be included because of time constraints. Other enhancements will be entirely new features. As with the V3.00 upgrade, organizations other than TBE are responsible for some of the software improvements.

Major enhancements of EADSIM V4.00 will include improvements in Electronic Warfare. Currently, electronic warfare is limited to the jamming of communications systems and radar sensors. EADSIM V4.00 will model counterforce, which involves a strike against other surface-to-surface missile sites. This will allow automatic targeting, scheduling, and launch of surface-to-surface missile engagements within the simulation. As the model currently exists, all surface-to-surface engagements are pre-scripted. Air defense artillery (ADA), also known as anti-air artillery (AAA), is another new feature of the V4.00 model. The air defense artillery model will allow the user to employ such assets in a scenario. Future improvements in this area may include the modeling of directed energy weapons. Such systems have been sucessfully modeled using a gun with

a very high muzzle velocity and a high probability of kill. The actual simulation of an energy weapon beam has yet to be accomplished within EADSIM.

Other new features of V4.00 will include modeling of track management, incorporation of an air tasking planner, and the addition of a database management system. The commercially available *Oracle* database manager has received much attention because the software for the Extended Air Defense Test Bed (EADTB) is being developed to be compatible with *Oracle*. In order to achieve commonality, it would be logical for EADSIM to use the same database management system. [Ref. 21]

3. The Extended Air Defense Test Bed

The purpose of the Extended Air Defense Test Bed (EADTB) is to provide a simulation and analysis capability far beyond that of EADSIM. As a follow on to EADSIM, which is considered to be its prototype, EADTB will also be a many on many, two sided, fully interactive theater level simulation. EADTB is several orders of magnitude more powerful than EADSIM, but is not intended to replace it. It is planned for one system to complement the other and that EADSIM users provide data for the EADTB program as it evolves. Besides studying present air defenses, EADTB will be able to analyze future defenses, evolving air threats, and technology applications. EADTB will be used by material developers, combat developers, and operational commanders. It will provide decision makers with a basis for optimizing, prioritizing, and maximizing scarce research and development resources. [Ref. 22]

An EADTB node is a complete hardware and software system. Each node will have its own Convex *3840* mainframe computer. This system has similar processing

capabilities to that of the Cray Y-MP EL mainframe of the NPS Visualization Lab. The software used by EADTB is written in Ada, C, and Fortran-77. A node can be run stand alone, or can be networked with other EADTB nodes. The first node is scheduled to receive an initial operational capability (IOC) in October 1993 at the Advanced Research Center in Huntsville, Alabama. The second node will go to the Army Air Defense Artillery School at Ft. Bliss, Texas. The third node is slated for use at the SHAPE Technical Center in The Hague, Netherlands. An additional, fourth site may by be installed at Kirkland AFB, New Mexico. Potential user sites and network connections include the Naval Surface Weapons Center (NSWC), the Naval Air Warfare Center (NAWC), the Air Force Studies and Analysis Agency (AFSAA), and the Army Concepts and Analysis Agency (CAA). [Ref. 22]

The EADTB program is a joint project and has received active Air Force participation from program inception. Because air defense is a joint mission, plans include the modeling of all air defense issues, including Naval anti-air warfare. In this light, it is expected that EADTB will receive increased Navy participation. All naval AAW systems should be modeled in EADTB, especially Aegis.

4. EADSIM Unclassified Database

The Space and Strategic Defense Command has sponsored CAS Incorporated to develop a standard unclassified database for EADSIM. The values within the database will more closely represent real world specifications. The standardized database will have documented references. Previously, many EADSIM users were reluctant to use the existing values within the EADSIM library because of their questionable validity. As a

result, the users were spending time developing their own research data for EADSIM use. The new database will also include on-line assistance for deploying platforms and systems during Scenario Generation. The first segment of the database will be available at 31 July 1993, it will include aircraft parameters. The second segment, available 31 October 1993, will cover weapons and communications devices. The third segment, available 30 November 1993, will cover protocols. The fourth, available 15 February 1994, will cover sensors. The fifth, available 15 March 1994, will cover RCS and Jammers. The sixth, available 15 April 1994, will cover rule sets. [Ref. 23]

B. OTHER CONCEPTS TO INCORPORATE INTO EADSIM

The author has noted other faults within EADSIM and has made the following suggestions. Some of these suggestions are aimed at fixing major shortcomings of the model, while others are intended to add a higher level of fidelity.

1. Missile Fly-out

The author is not the only user who feels that the greatest flaw in EADSIM as a learning tool is a lack of missile fly-out. This fact has been mentioned several times throughout this thesis and was the subject of discussion at the last User's Group conference. To conduct an explicit missile fly-out, an existing missile model must be integrated into EADSIM, or a new module must be created.

2. Improve Fidelity of Naval Assets

Currently EADSIM models naval assets in the same manner as it does ground assets. To improve fidelity of naval AAW, specific rule sets should be developed for

ships. An aircraft carrier, for example, acts as a floating air base within EADSIM. What is not modeled are all the C^3 capabilities and the self defense weapons of a carrier. To resolve this dilemma, an Aircraft Carrier rule set should be created. Guided missile ships also suffer from the same lack of fidelity. The Aegis cruiser used in the scenarios developed for NPS, was modeled using modifications of the Patriot missile and radar systems. Because of their superior sensor, weapon control, and missile launch capabilities, there should be a special rule set for Aegis ships. Modeling of other ships, such as frigates and New Threat Upgrade (NTU) cruisers is also difficult to accomplish. The EADSIM library needs to incorporate common naval search radars such as the SPS-48E and the SPS-49, and missile fire control systems such as the Mk 76 and Mk 92. In addition, EADSIM needs to include varients of the AN/SLQ-32 ESM/ECM suite, which is installed in virtually every surface combatant in the U.S. fleet.

3. Weapon Modification

An improved selection of weapons, especially air-to-air and surface-to-air missiles, would enable the user to "mix" the weapons load of a unit being modeled. Naval SAM's are particularly lacking in the current EADSIM library, where only one type of the Standard Missile family can be found. Other weapons, such as NATO *SeaSparrow* and the Rotating Airframe Missile (RAM) are not included in the library. The Navy's premier AAM, Phoenix, is also not modeled. To be able to more accurately model naval AAW, these weapons must be included in the EADSIM library.

Another desired feature would be the capability to model warhead effects. Currently, weapons can either miss or kill a target. The only method to change the

lethality of a weapon is to vary the default P_K. Other AAW models have incorporated end game effects. This would add a tremendous amount of fidelity to the engagement aspect of a simulation.

C. EADSIM INTERFACE WITH OTHER MODELS

1. Patriot Tactical Operations Simulator

The Patriot Tactical Operations Simulator, PTOS, is the Army's main training device for the Patriot missile system. By interfacing PTOS with EADSIM, the individual strengths of the two models can complement one another. This interface allows PTOS to act as Patriot battery within an EADSIM scenario. The use of mixed fidelity models allows, in this case, allows man-in-the loop operations within EADSIM. As such, EADSIM becomes a training tool and an analysis tool. [Ref. 24]

2. TAC Brawler

The motivation behind the integration of EADSIM and TAC Brawler was that no simulation does everything. Analysts must frequently use several models, each of which handles only a part of the overall picture. They then have to try to combine the results from different studies to produce a sensible final answer. One solution is to combine several models in such a way that each handles the parts of the scenario that it does best. By combining EADSIM with TAC Brawler, higher fidelity air-to-air engagements are possible. TAC Brawler provides aircraft aerodynamics, air-to-air missiles, air intercept radar, other avionics, and a pilot model. It also provides for improved SAM modeling with a reactive air target, but is not a substitute for a true SAM model. [Ref. 25]

3. Ground Attack Fighter Bomber Model Software

The Ground Attack Fighter Bomber Model Software, GAFMS II, is another integration of existing models. In this case, GAFMS acts as a cradle for EADSIM, FLAPS (Force Level Automated Planning System), and RAIDES (Rapid Air Defense Evaluation System). FLAPS is a model used to plan air attacks. It allocates air assets, plans routes, and assigns targets. RAIDES is a model used for air defense planning. It chooses air defense sites and orients air defense sensors. GAFMS provides a common database that allows the different models to inter-operate. By providing the interface, GAFMS allows easy integration of other models. A problem with such an integration is the ammount of computer code needed to accomplish the task. GAFMS requires more coding than any of the models that it integrates (320,000 + lines of code for GAFMS, vs. 300,000 lines of code for EADSIM, 100,000 lines fo code for RAIDES, and 94,500 lines of code for FLAPS). [Ref. 26]

D. A COMPARISON WITH ACES/PHOENIX

1. Brief Description of ACES/Phoenix

ACES/Phoenix is another air defense model that is being studied in a thesis project parallel to this thesis. Lieutenant John Armantrout is using the ACES/Phoenix model in his thesis *Adaptation of ACES/Phoenix for Survivability and Lethality Assessment at the Naval Postgraduate School.*

> ACES/Phoenix is a software tool that enables an analyst to perform efficient modeling and simulation of aircraft survivability and air defense lethality in a user-friendly computer environment. ACES/Phoenix uses community accepted models for simulating surface-to-air missile engagements, radar directed gun engagements, and air-to-air missile engagements against a single aircraft. [Ref. 27]

ACES/Phoenix is a software package that allows simultaneous operation of a variety of high fidelity models. The Adaptive Combat Environment System, ACES, provides the cradle for the different models to interface with. Phoenix provides a common graphical user interface for the software package.

2. Similarities Between the Models

Although the two models are designed to simulate different aspects of the air defense spectrum, they have some similarities. The main similarity is that they both operate under UNIX in a graphical user interface. Both models have their own windowing system and are capable of modeling an entire integrated air defense at any location on the Earth. EADSIM and ACES/Phoenix allow modification of the systems being modeled, can be run Monte Carlo perform terrain modeling (using DMA data), and have a radar clutter map (EADSIM V3.00). In addition, both models are certified to run at a Secret level of classification.

3. Differences Between the Models

a. Advantages of EADSIM

The primary advantage of EADSIM is that it can model a two sided, many-on-many scenario. ACES/Phoenix is limited to a single sided, one-on-many (Blue aircraft against Red air defense) scenario. EADSIM can model naval warships, ACES/Phoenix can not. EADSIM has superior C^3I modeling and provides for modeling of multiple tiers of C^3I networks.

ACES/Phoenix can only model one tier of of a command and control network. Another advantage of EADSIM is its graphical capabilities with scenario playback. A benefit that EADSIM also enjoys is its widely accepted use (over one hundred registered user sites) and the support of SSDC. ACES/Phoenix, although it is a SURVIAC (Survivability/Vulnerability Information Analysis Center) supported model, does not have such a large user base.

b. Advantages of ACES/Phoenix

The major advantage of ACES/Phoenix is that it is an engineering level model. As such, it has much higher fidelity in many areas of air defense modeling. These include missile fly-out, aspect dependent radar cross section, specific IR signatures for aircraft, and modeling of explicit kill and endgame effects. None of these features are available within EADSIM. Another major advantage of ACES/Phoenix is that it may run on any UNIX based computer workstation. ACES/Phoenix has an integrated cradle of community accepted models that also allows for easy integration of other models. Integration of other models with EADSIM requires a great deal of coding and has not been attempted with many models. Another clear advantage of ACES/Phoenix is that it is relatively easy to use. EADSIM is difficult to learn and even more difficult to use.

4. Computer Models as Tools

In either case, EADSIM and ACES/Phoenix are designed as educational and training tools. They both serve a purpose in analysis of different aspects of air defense. With a shrinking defense budget, researchers will have to turn to computer modeling and simulation to determine the feasibility of future aircraft and weapon system designs.

XIII. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

1. Model Selection, Installation, and Operation

The primary goal of this thesis was to develop a capability to model naval AAW systems at NPS. Before the actual model selection, a variety of air defense models were investigated. Most of the potential choices were from the *Catalog of Wargaming and Military Simulation Models*. The catalog lists the capabilities of the models as well as the hardware requirements. To make a selection, the model had to meet the prerequisites of this project and the equipment in which to install the model had to be available or attainable. The outcome of this selection process was the choice of the Extended Air Defense Simulation (EADSIM).

EADSIM is a sophisticated and powerful model that can simulate many aspects of air warfare. It <u>requires</u> a Silicon Graphics computer workstation with a 24-bit graphics plane. Other recommended system capabilities are a minimum of 64 Megabytes of RAM and 1.2 Gigabytes of hard disk storage space. The Computer Center Visualization Lab has a network of SGI workstations, one of which is a *Power Series 380/VGX*. This computer has eight parallel processors and 128 Megabytes of RAM. In other words, it more than met the system requirements of EADSIM. There was, however, a lack of available hard disk storage space in the Visualization Lab. Therefore, a new 2.1 Gigabyte "fast SCSI" hard disk was acquired.

Once EADSIM was selected, a copy of the software had to be acquired and installed. Representatives from Teledyne Brown Engineering and the Space and Strategic Defense Command brought a copy of the EADSIM software to NPS for installation, demonstration, and instruction. The installation process was difficult. The open purchased hard disk had not yet arrived and another storage site for EADSIM had to be found. The Physics Simulation Lab has a Sun Systems (*SPARCServer*) file server that had more than adequate storage space available. Loading and operating the EADSIM software over the ethernet network proved to be a tedious process. This was further complicated by corrupted software. The tape provided by TBE had been previously run on a workstation that had a "Beta" copy of EADSIM Version 3.00 installed. This reformatted all the scenario information on the Version 2.07 tape provided. The net result was that a working copy of EADSIM was not available at NPS for another six weeks. A new copy of the V2.07 software was obtained and installed directly onto the new hard disk that had also arrived.

Operation of EADSIM is conducted through a graphical user interface (GUI). The GUI allows the user access to the various routines and on-line tools of EADSIM. To model the various participating units of a scenario, a library of platforms is available as part of the database. These platforms may be modified by the user, as well as the weapons, sensors, and communications equipment. Actual platform performance within a scenario is governed by Rule Sets. These rule sets may be further modified to meet the needs of the user. The selection of platforms and rule sets is conducted from the Scenario Generation routine within EADSIM. Scenario Generation allows the initial laydown of

a scenario over a graphical map file. Once the original laydown is made, the scenario can be saved to hard disk, edited, or run.

2. Scenarios

Two sets of scenarios were developed by the author for future use in AE3705 "Air Defense Lethality" and AE3251 "Aircraft Combat Survivability". The first set of scenarios was created for AE3705. It required the modeling of naval warships operating in a hostile AAW environment. Anti-ship cruise missiles and attack aircraft were selected from the EADSIM library as the adversary. An Aegis cruiser, a destroyer, and an aircraft carrier were selected as the naval platforms conducting the air defense. The first scenario had the cruiser operating autonomously against the threat. The second scenario added the destroyer, which was equipped with only short range missiles. This scenario was run twice. The first run had the ships operating their weapon systems independently. The second run had both ships' weapon systems controlled by the cruiser over a command network. The third scenario added the aircraft carrier. Because the aim was to model shipboard air defense, the carrier's air wing was deliberately omitted. This scenario was also run twice, first with the cruiser exercising tactical control of the weapon systems, and again with the carrier exercising tactical control.

The second set of scenarios was designed for use in AE3251. It models a strike by Navy aircraft against a defended airfield. The airfield is defended by a network of SAM batteries. The first scenario has a flight of F/A-18 *Hornets* conducting a strike against the airfield with gravity bombs. The second scenario gives stand-off weapons to the *Hornets* to minimize their exposure in the SAM envelope. The third scenario adds

anti-radiation missiles to the strike package, along with jamming support from an EA-6B *Prowler*. The fourth scenario puts defensive counter air on CAP stations above the airfields. The enemy fighters are a mix of MiG-29 *Fulcrums* and F-1 *Mirages*. The fifth scenario provides escort fighter cover for the strike by adding F-14 *Tomcats*. The purpose of this gradual escalation is to show the cause and effect of various offensive and defensive measures on aircraft survivability.

3. Execution

Scenario Execution, another EADSIM routine, allows the actual simulation of the platforms involved. It is conducted by four run-time processes within the program. These processes are Detection, C^3I, Propagation, and Flight Processing. Once a scenario is run, the results are sent to the Post Processor routine and to the Scenario Playback routine. Both routines offer the user the opportunity to see the scenario results. The Post Processor produces data files for detections, engagements, and communications. These files may be turned into a hard copy printout or downloaded into an off-line application such as a spreadsheet. The graphical Scenario Playback provides perhaps the most striking feature of EADSIM. It produces an animated playback of a scenario run that is viewed on-line, directly on the computer monitor.

4. Probability of Kill

A study of the EADSIM weapon performance model was conducted as part of this thesis. The default values for the probability of kill of individual weapons were modified. The results were examined to determine the overall effect of P_K within a simulation. Generic models of five types of surface-to-air missiles were created. These SAM's were

point defense (5 km), short range (15 km), medium range (50 km), long range (100 km), and extended range (200 km) missiles. The study looked at each weapon while P_K was altered for a single engagement. Multiple Monte Carlo runs were then conducted.

5. Future Growth

EADSIM continues to evolve and meet the needs of the user. The next edition of the software is Version 3.00 and is scheduled for release in late June 1993. The V3.00 release corrects some flaws that currently exist in the model and adds new features to increase its fidelity. Among the major enhancements are the addition of P_k tables, improved kill assessment modeling, an improved aircraft flight model, infra-red sensors and IR weapon seekers, an enhanced radar model, a non-graphical post processor, a new ballistic missile model, and improved Monte Carlo execution. These features are designed to add utility to the model and to make it more user friendly. Version 3.00 will also be compatible with the Sun Systems *SPARCStation 2* series workstation. Although model operation will be slightly different, the Sun compatibility will enable increased use of EADSIM at organizations without Silicon Graphics equipment.

Another major revision of EADSIM is scheduled for December 1993 with the release of Version 4.00. This release will incorporate new features that were not ready for inclusion into V3.00. Major enhancements of V4.00 include electronic warfare improvements, modeling of counterforce, modeling of AAA, track management, air tasking, and a database management system.

The follow-on project to EADSIM is EADTB, the Extended Air Defense Testbed It is scheduled for an initial operational capability (IOC) of October 1993 and offers a

much higher level of simulation and analysis capability over EADSIM. EADTB operates on a dedicated main frame computer and can receive inputs from EADSIM and other EADTB nodes. Although EADSIM was originally developed as the EADTB prototype, its success has ensured that it will continue to grow. It is planned for EADSIM and EADTB to complement each other with a compatible database management system.

B. CONCLUSIONS

1. EADSIM is an Effective Tool

EADSIM is a highly effective theater level model and analysis tool. Although emphasis is placed on C^3I operations, it's versatility allows it to model many aspects of air warfare. Air-to-surface, air-to-air, and surface-to-air engagements may all be conducted within a simulation. In addition EADSIM can model theater ballistic missile employment and theater ballistic missile defense. It excels in the simulation of a large variety of combat platforms on land, at sea, and in the air. These platforms may be modified by the user to reach a higher level of fidelity, or to model systems not contained in the EADSIM library.

EADSIM is as flexible as it is versatile. The multiple run-time processes and the Monte Carlo execution allow the user to easily simulate numerous scenarios. The Post Processing reports provide the analyst with a variety of simulation results. The analyst may require all the simulation results, or may need to see only a single aspect of the simulation. The graphical playback capability is one of the most outstanding features of EADSIM. Simulation results may be viewed immediately after the completion of a scenario run.

2. EADSIM is a Complex Model

EADSIM is a very complex computer model. Its installation and operation require the appropriate computer hardware for it to be effective. The large and multiple data files associated with a simulation can become cumbersome, particularly as a scenario grows. EADSIM operation is not intuitive, and a high level of experience is required for user proficiency. A working knowledge of UNIX is also necessary to troubleshoot and debug problems within the model. The learning curve on the software is difficult, especially if the user is solely relying on the User's Manual and associated documentation. The available on-site training is a necessity for a new or first time user. Even with user experience, EADSIM is not particularly user friendly. What appears to be a successful scenario run may not be at all. For example, certain platforms may not properly employ their weapons, or may not employ them at all. This can result in the user having to page through numerous on-screen menus to find the source of the problem. The final difficulty encountered is that a scenario developed on one workstation may not run on another. The author received a pre-built scenario from an outside source, but the scenario would not run in the Visualization Lab. Additional troubleshooting and debugging are required for this type of problem, adding to the "user unfriendliness" of the program.

Some of the disparities of EADSIM are not limited to the actual hands-on operation of the model. Many of the problems encountered are the result of a lack of fidelity. EADSIM does not attempt to simulate all aspect of AAW, but simplistic modeling of real world occurrences can not be considered as an effective way of solving problems. The single greatest flaw encountered by the author is a lack of accurate

weapon modeling. An explicit missile fly-out model may not be necessary, but a single probability of kill for a weapon is not realistic. Another fault found by the author is a lack of adequate modeling of naval, specifically shipboard, systems. There is not a single naval search radar or fire control radar in the EADSIM library. EADSIM does allow the modeling of those systems, but the user needs prior knowledge of the system's parameters to do so.

3. Upgrades Will Correct Some Shortcomings

The software changes being incorporated into EADSIM Version 3.00 and Version 4.00 will correct some of the faults found in the model. As the model grows and evolves more improvements will be made to assist the user and to attain higher levels of fidelity. In addition, more missions, platforms, and systems should find their way into the model. Specific problems within the software code will continue to be rectified via the Software Change Request. Each SCR is reviewed and a board determines if the revision is to be included in the next software release.

C. RECOMMENDATIONS

1. Adaptability for Student Use

a. UNIX Training

In order for a student to become proficient in the use of EADSIM, they must first become adept in the UNIX operating system. The Computer Center offers a one hour Introduction to UNIX lesson several times each quarter. The material given in this lesson is an overview is and not sufficient to gain a working knowledge of UNIX. Academic courses are offered from several departments that deal with working on UNIX

workstations. These departments also maintain computer laboratories where students can gain practical experience. The author took the PH2911 "Computational Physics" and PH4911 "Combat Systems Modeling" sequence from the Physics Department. Both courses provided an excellent overview on the use of UNIX, as well as providing practical experience on programming solutions to physical problems in *C*. As stated in the conclusions, a working knowledge of UNIX is essential for successful operation of EADSIM.

b. EADSIM Training

Because EADSIM is such a complex model and not user friendly, additional training in its operation is recommended. An EADSIM User's Course is sponsored by SSDC and offered by CAS Incorporated and TBE. The two week course may be exported to a command, or may be held in Huntsville, AL. Specially tailored one week courses may be presented depending on the user's needs and previous level of experience with the model. The author recommends that if EADSIM continues to be used at NPS, then an experienced user should be on the staff to assist and further train student users. This staff member should take the EADSIM User's Course in Huntsville. By taking the course away from NPS, normal duties will not detract from the training. The staff user should also attend the EADSIM User Group Conferences that are held several times per year. This will ensure that NPS maintains the latest information and receives the future software releases.

2. Continued EADSIM Use at NPS

a. Computer Center Visualization Laboratory

The Visualization Lab should continue to maintain its status as a registered EADSIM user. The SGI *Power Series 380/VGX* is equipped with the hard disk purchased for this project and has the processing power to perform any EADSIM operation. All system documentation is available in the lab and other SGI workstations are available for use. Students with mainframe computer accounts now have access to the Visualization Lab. This will allow the potential use of EADSIM at NPS by virtually any student who desires. For multiple users, care must be taken by the system administrator concerning write privileges of critical files. The Visualization Lab has recently received a new SGI workstation, the *Indigo*^{2}. It is a top-of-the-line desktop system and has the latest available microprocessor, the R4400. This workstation has equivalent processing capability to the 380/VGX and could also run any EADSIM application. The other SGI workstations in the lab are older systems and should be limited to running smaller scenarios and playback files.

b. Wargaming Laboratory

The Wargaming Laboratory is a secure facility that can run classified simulations up to the SECRET level. A SECRET database is available for EADSIM and could be set up for use in the Wargaming Lab. The lab is currently equipped with Sun *SPARCStation 2* workstations and could run EADSIM V3.00. In addition, an SGI *Indigo Elan* is on order, equipped with the requisite 24-bit graphics plane. The *Indigo Elan* has nearly the same capabilities of the *Indigo*^{2} and would be ideal for EADSIM operation.

c. Installation In Other Computer Laboratories

There are numerous other computer laboratories across the NPS campus. Some may be suited for EADSIM use. The Department of Aeronautics and Astronautics computer lab has ordered new Silicon Graphics workstations, three of which will be equipped with a 24-bit graphics plane. This would be an ideal site for EADSIM, since one of the results of this project was the development of scenarios for AE3705 and AE3251. This will also allow for closer control over software use, as open access to this lab is not permitted.

The Operations Research Department also has a registered user. LCDR Mark Rios is writing his thesis "Optimum Aegis Ship Stationing for Active Theater Missile Defense" with the assistance of EADSIM. This department, unfortunately, does not have Silicon Graphics or Sun computers. Should EADSIM be further developed for the Hewlett Packard workstation, which is available to Operations Research Department students in Glasgow Hall, then work could be done there. Other curricula that could use that facility are National Security Affairs and Command, Control, and Communications.

The Computer Science Department has its own Silicon Graphics workstation lab. Much of the work accomplished by students of this curriculum involves computer programming. The EADSIM source code could be requested by the department and students could perform source code modifications, perhaps as thesis projects. Many of the software changes that appear in EADSIM software revisions are performed as site modifications by other users.

3. Many Users

Because EADSIM is so versatile and because many curricula may have a need for such a simulation, it is appropriate that the model be maintained at NPS. The potential for increased use is such that more sites at NPS could install the model. The Air Force Institute of Technology (AFIT) is a registered user as are numerous other defense research agencies. Although EADSIM is an Army project, it is used jointly throughout the Department of Defense and by many defense contractors. Appendix F is a current listing of EADSIM registered users. A powerful tool such as EADSIM can help get the most out of reduced research budgets.

APPENDIX A

A Selected List of AAW and Air Defense Models and Simulations

With the exception of ACES/Phoenix, which is a SURVIAC model, the following list of anti-air warfare and air defense models and simulations were selected from the Defense Technical Information Center (DTIC) *Catalog of Wargaming and Military Simulation Models*. All model some aspect of naval AAW or air defense and were considered for use in this project.

1. ACES/Phoenix

Model Description: An integration of several AAW simulations into a single graphical interface.

System Requirements: Sun *SPARCStation* or any Unix workstation.

Operating System: UNIX.

Language: Various.

Status: In use at Air Force Operational Test and Evaluation Center, Naval Postgraduate School, Naval Air Warfare Center Weapons Division, Strategic Joint Intelligence Center.

2. Ada SAM

Model Description: A surface to air missile analysis model developed by the Air Force.

System Requirements: VAX.

Operating System: VMS.

Language: Ada.

Status: IOC 1987, used by several defense contractors.

3. **ADMRALS** - Attack and Defense of Maritime Resources in Adverse Locales

Model Description: Developed by NSWC Dahlgren for regional naval battleforce and fleet defense analysis.

System Requirements: Six Sun Workstations for parallel processing and one Silicon Graphics *Personal Iris* for graphics.

Operating System: UNIX.

Language: FORTRAN, Pascal, C.

Status: Funding ended FY '92 before model became operational.

4. **ASBAT** - Air/Sea Battle Model

Model Description: A multi-threat Red on Blue engagement of naval vessels in open ocean waters (no geography).

System Requirements: VAX or Sun.

Operating System: VMS or UNIX.

Language: FORTRAN.

Status: IOC 1988, in use at CINCPACFLT.

5. **AWSIM** - Air Warfare Simulation

Model Description: Developed by Headquarters U.S. Armed Forces Europe for Air/Land battle training. Limited naval applications.

System Requirements: VAX.

Operating System: VMS.

Language: FORTRAN. Ratfor, C.

Status: IOC 1983, in use at all NATO commands.

6. COMMANDER V

Model Description: A tactical air, land, and naval operations model.

System Requirements: VAX.

Operating System: VMS.

Language: FORTRAN, Simscript II.

Status: IOC 1989, in continual use and development by Science Applications Applications Corporation for a variety of commercial and government customers.

7. COSYCAT - Combat Systems Capability Evaluation Tool

Model Description: Single ship surface-to-air missile engagement tool, designed to evaluate the Standard Missile (Tartar/SM-1 [MR]).

System Requirements: Hewlett Packard 9845C.

Operating System: UNIX.

Language: HP Basic.

Status: IOC 1987, no longer in use.

8. EADSIM - Extended Air Defense Simulation

Model Description: Air, land, and naval simulation involving theater level air defense scenarios. Designed to evaluate force on force outcomes.

System Requirements: Silicon Graphics *4D Series* Workstation (or higher).

Operating System: UNIX.

Language: C.

Status: IOC 1989, in use by all services, many contractors, and some allies.

9. EADTB - Extended Air Defense Testbed

Model Description: Follow-on to EADSIM, higher fidelity applications on mainframe computer.

System Requirements: Convex mainframe.

Operating System: UNIX.

Language: C.

Status: Under development, expected IOC October 1993.

10. FACTS - Fleet AAW Model for Comparison of Tactical Systems

Model Description: AAW analysis model of up to two Aircraft Carriers in a single CVBG. Blue shipboard systems defending against Red ASCM's.

System Requirements: VAX.

Operating System: VMS.

Language: Pascal.

Status: IOC 1983 in use at Naval Surface Warfare Center.

11. IWSS - Interactive Weapon System Simulation

Model Description: Simulation of air, land, and sea based weapons in offensive and defensive actions.

System Requirements: VAX.

Operating System: VMS.

Language: Simscript II, FORTRAN, DCL.

Status: IOC 1989, used by General Dynamics.

12. MARS - Multi Warfare Assessment and Research System Model

Model Description: Naval warfare model being developed by NSWC White Oak Lab. Designed to study the employment of naval units operating in a multi-threat environment.

System Requirements: Any Workstation (DEC, HP, SGI, SUN, VAX), IBM PC, or Macintosh II.

Operating System: UNIX, MS DOS, or System 7.

Language: Modsim, Clips.

Status: Not available, still under development, expected IOC was January 1992.

13. SLAM - Ship Level Analysis Model

Model Description: Single ship or single system performance against AAW threat.

System Requirements: Sun.

Operating System: UNIX.

Language: Simscript II, Simgraphics.

Status: IOC 1990, in use at Naval Surface Weapon Center.

14. THREAT

Model Description: A battleforce AAW model intended to calculate CVBG vulnerability, recommend transit routes and determine CAP requirements.

System Requirements: VAX.

Operating System: VMS.

Language: FORTRAN.

Status: IOC 1989, in use at CINPACFLT, Naval Ocean Systems Center.

APPENDIX B

EADSIM User's Group Lessons Learned

The most recent EADSIM User's Group conference was held 23 - 25 February 1993 at Teledyne Brown Engineering in Huntsville, Alabama. The author was in attendance. During the three day seminar, a variety of topics were presented by several contractors and representatives of all military branches. Of note, however, was a marked lack of Navy participation at the User's Group. Of the nearly one hundred attendees, only two had Navy affiliation. Largely, the Army and the Air Force have had the strongest interest in EADSIM.

Most of the presentations concerned recent analysis work done with EADSIM. Others covered new modifications to the software that may make their way into the baseline code. Interfaces with other simulations and simulators were presented. These were relevant in that they addressed EADSIM as a training aid rather than an analysis tool. Advanced training aids may come to the forefront as training budgets shrink. EADSIM has shown the potential to be one of them.

The Extended Air Defense Testbed (EADTB) was briefed by the Army Space and Strategic Defense Command Testbed Product Office. The presentation not only stressed the evolution of EADSIM into EADTB, but also that EADSIM use will continue to be important to provide data for EADTB use. Despite the arrival of EADTB later this year, EADSIM will continue to grow. The maturity of EADSIM and the continuous improvement of the model have made it a favorite among its users.

The most controversial topic of the User's Group meeting was the Joint Air Defense Operations and Joint Engagement Zone Office (JADO/JEZ) briefing on Verification, Validation and Accreditation (VV&A). The JADO/JEZ Office has done limited work on verifying certain aspects of the EADSIM code. This effort has been rejected by some who state that VV&A is equivalent to a mathematical proof of the model's accuracy. Of course, such a measure is impossible for a code as complex as EADSIM. Others see VV&A as a measure that makes the model acceptable. Although JADO/JEZ has tried to verify and validate some of the logic in the software, JADO/JEZ will not attempt a complete validation of EADSIM.

The next User's Group is scheduled to meet in June 1993 to coincide with the release of EADSIM Version 3.00. It has been a traditional practice to hold the conference concurrent with the release of a new version of the code. EADSIM Version 4.00 is planned for release in December 1993.

APPENDIX C

EADSIM Scenario Guide

The following is a guide for students enrolled in AE3705 "Air Defense Lethality" and AE3251 "Aircraft Combat Survivability". Scripted scenarios have been developed for use in these courses and are currently available on the Silicon Graphics workstations of the Computer Center Visualization Laboratory. The scenarios have been pre-run such that they require only access of the playback files and no previous experience with EADSIM. Consult the EADSIM User's Guide (Appendix D) for specific operational procedures to view these scenarios on the Silicon Graphics workstations of the Visualization Lab. Students who desire further information on the model may consult the EADSIM manuals which are available in the Visualization Lab. By viewing the scenario playback files, the student can see the cause and effect of several aspect of AAW.

1. Naval AAW Scenarios

This set of scenarios have been developed for AE 3705 and are designed to represent the air defense of naval forces operating in littoral waters. The ships are operating in the eastern Mediterranean Sea off the coast of Lebanon. The threat is a combination of anti-ship cruise missiles (ASCM's), both shore launched and air launched, and tactical attack aircraft. The ASCM's are are of the *Silkworm* family, the shore launched missiles being launched from Transporter Erector Launchers (TEL's) and the air launched missiles bieng

launched from Tu-16 *Badger* bombers. In addition, MiG-23 *Flogger* attack aircraft armed with standoff weapons and gravity bombs are also ready for attack.

The first scenario run (AAW_1) has a *Ticonderoga* (CG-47) class guided missile cruiser operating autonomously in the vicinity of the threat. The Aegis cruiser is equipped with the AN/SPY-1 phased array radar and the SM-2 *Standard* Missile. All sensors are operational and all launchers are loaded. The second scenario adds a Spruance (DD-963) class destroyer operating with the cruiser. This ship's sensors are limited to two-dimensional air search radars and it is equipped with the NATO *SeaSparrow* (RIM-7) point defense missile system. This second scenario is run twice, with the first run (AAW_2) having the ships operate independently. The second run of this scenario (AAW_3) gives tactical control of both ship's weapon systems to the cruiser. This represents the use of tactical data links and a command and control structure. The third scenario adds an aircraft carrier to be protected against the incoming threat. The organic assets of the carrier, its aircraft and point defense systems, are not not available for use. Two runs of this scenario are conducted; one with tactical control on the cruiser (AAW_4), and the other with tactical control on the carrier (AAW_5).

2. Naval Strike Aircraft Scenarios.

These scenarios have been developed developed for AE 3251 and simulate an aircraft strike against defended targets. The targets in this set of scenarios are airfields in the vicinity of Beirut. They are defended by an integrated network SAM's consisting of SA-8 and SA-11 batteries. The SAM batteries are also supported by ground based early warning radars.

The first scenario (Air_Strike_1) is an unprotected raid on the airfields by two flights of eight F/A-18 *Hornets*. The attack fighters are armed with only gravity bombs. In the second run of this scenario (Air_Strike_2), the attacking aircraft are given stand-off weapons to avoid exposure to the SAM envelope. The third run of the scenario (Air_Strike_3) adds stand-off jamming and anti-radiation missiles. An EA-6B *Prowler* is provided for jamming services and two A-6E *Intruders* are added to each flight armed with the High-speed Anti-radiation Missile (HARM). The fourth run (Air_Strike_4) puts Defensive Counter Air in the form of MiG-29 *Fulcrum* and MiG-25 *Foxbat* fighters up against the strike. The enemy CAP also has support of ground control intercept (GCI) radar. The fifth scenario run (Air_Strike_5) adds escort fighters to the strike package. In this case, two sections of F-14 *Tomcats* provide cover against the enemy fighters.

APPENDIX D

EADSIM Visualization Lab User's Guide

This guide is designed for use by AE3705 "Air Defense Lethality" and AE3251 "Aircraft Combat Survivability" students for the scenarios described in Appendix C. The playback files for the scenarios are available for viewing on the Silicon Graphics workstations of the Computer Center Visualization Laboratory. Students must obtain a mainframe account, the log in for the Visualization Lab uses the same password as the mainframe. The following procedure will take a student through the appropriate menus so that the scenario playback files can be viewed.

Procedure:

1. **Log on** to any SGI workstation.
2. From the *IRIX* window environment, with left mouse button, click on **Programs**.
3. From Program window, with left mouse button, click on **EADSIM Training**.
4. Wait for program to load.
5. Hold right mouse button, note menu bar at top of display.
6. Drag cursor to **Applications** without lifting on right mouse button.
7. Continue to drag down to highlight **Scenario Playback**, lift right mouse button.
8. Wait for Scenario Playback Application to load.
9. From the scenario playback window, hold right mouse button, note new menu bar at top of display. Scenario Playback window must be active to get the new menu. **NOTE**:

An active window is bordered in red. To activate a window, click the left mouse button with the cursor inside the window.

10. With right mouse button, drag to **Scenario Playback** without lifting .

11. Continue to drag down to highlight **Load Playback File,** lift right mouse button.

12. From **Start Playback** window, select appropriate directory (**AE3705** or **AE3251**).

13. With left mouse button, click on appropriate directory.

14. Note highlighted title name and playback file name at bottom of window (they should be the same).

15. With left mouse button, click on **Select**.

16. From **Start Playback** window, select title of scenario run to be viewed;

AAW_1	**Air_Strike_1**
AAW_2	**Air_Strike_2**
AAW_3	**Air_Strike_3**
AAW_4	**Air_Strike_4**
AAW_5	**Air_Strike_5**.

17. With left mouse button, click on appropriate scenario title.

18. Note highlighted playback file and playback file name at bottom of window (they should be the same).

19. With left mouse button, click on **Select**.

20. Wait for computer to build map.

21. When map is built, note control panel window at top right corner of display.

22. With left mouse button, click on **Run**.

23. View scenario playback.

24. To hold playback file, click on **Pause** with left mouse button.

25. To increase playback speed, click on the " + " token with the left mouse button.

26. To slow playback speed, click on the " - " token with the left mouse button.

27. To fast forward to the end of the playback file, click on the " **FF** " token.

28. Once viewing is complete, click on **Rerun** to view again, or click on **Abort** to finish.

29. To load and view another file, follow procedure from step 10.

30. To exit Scenario Playback; hold right mouse button and drag cursor to **Scenario Playback**, without lifting, drag down to **Quit**, drag right to **Confirm**, lift right mouse button.

31. To exit EADSIM, hold right mouse button and drag cursor to **Applications**, without lifting, drag down to **End EADSIM Session**, drag right to **Confirm**, lift right mouse button.

32. To log off SGI workstation, hold left mouse button, drag to **Log Off**, lift left mouse button.

33. Click on **Yes** with left mouse button to confirm.

APPENDIX E

EADSIM Post Processing Reports

The following is an excerpt from a computer generated output file from the EADSIM Post Processor. These reports are from a scenario run of the Naval AAW scenario discussed in Chapter IV, Chapter V, Appendix C, and Appendix D. It is a history report, and gives a chronological listing of events that occurred during Scenario Execution. The actual report is approximately 150 pages in length, therefore, it is not included in it's entirety.

```
** Beginning execution... **
   CG-47.1 activated at time  - 00:00:00.000
   ENGAGE: CG-47.1 activated
   SILKWORM_1.5 activated at time  - 00:00:00.000
   ENGAGE: SILKWORM_1.5 activated
   BADGER_1.8 activated at time  - 00:00:00.000
   ENGAGE: BADGER_1.8 activated
   BADGER_2.9 activated at time  - 00:00:00.000
   ENGAGE: BADGER_2.9 activated
   SILKWORM_2.10 activated at time  - 00:00:00.000
   ENGAGE: SILKWORM_2.10 activated
   RED_BASE.11 activated at time  - 00:00:00.000
   ENGAGE: RED_BASE.11 activated
   SILKWORM_3.12 activated at time  - 00:00:00.000
   ENGAGE: SILKWORM_3.12 activated
   RED_ATTACK_4.13 activated at time  - 00:00:00.000
   ENGAGE: RED_ATTACK_4.13 activated
   RED_ATTACK_5.14 activated at time  - 00:00:00.000
   ENGAGE: RED_ATTACK_5.14 activated
   RED_ATTACK_6.15 activated at time  - 00:00:00.000
   ENGAGE: RED_ATTACK_6.15 activated
   STRIKE_1.16 activated at time  - 00:00:00.000
   ENGAGE: STRIKE_1.16 activated
   DD-963.17 activated at time  - 00:00:00.000
   ENGAGE: DD-963.17 activated
   RED_STRIKE_1.18 activated at time  - 00:00:00.000
   ENGAGE: RED_STRIKE_1.18 activated
   1    3 1    8 7 0
IFF: CG-47.1 vs BADGER_1.8: unknown by first scan rule
IFF: Target BADGER_1.8 is squawking.
IFF: CG-47.1 vs BADGER_1.8: unknown by interrogation of enemy
   TRK: CG-47.1 initiated track on BADGER_1.8.
   1    3 1   15 7 0
IFF: CG-47.1 vs RED_ATTACK_6.15: unknown by first scan rule
IFF: Target RED_ATTACK_6.15 is squawking.
IFF: CG-47.1 vs RED_ATTACK_6.15: unknown by interrogation of enemy
   TRK: CG-47.1 initiated track on RED_ATTACK_6.15.
   1    3 1   13 7 0
IFF: CG-47.1 vs RED_ATTACK_4.13: unknown by first scan rule
IFF: Target RED_ATTACK_4.13 is squawking.
IFF: CG-47.1 vs RED_ATTACK_4.13: unknown by interrogation of enemy
   TRK: CG-47.1 initiated track on RED_ATTACK_4.13.
   1    3 1    9 7 0
IFF: CG-47.1 vs BADGER_2.9: unknown by first scan rule
IFF: Target BADGER_2.9 is squawking.
IFF: CG-47.1 vs BADGER_2.9: unknown by interrogation of enemy
   TRK: CG-47.1 initiated track on BADGER_2.9.
   1    3 1   18 7 0
IFF: CG-47.1 vs RED_STRIKE_1.18: unknown by first scan rule
IFF: Target RED_STRIKE_1.18 is squawking.
IFF: CG-47.1 vs RED_STRIKE_1.18: unknown by interrogation of enemy
   TRK: CG-47.1 initiated track on RED_STRIKE_1.18.
  14    3 1   13 6 0
IFF: RED_ATTACK_5.14 vs RED_ATTACK_4.13: friendly by first scan rule
```

```
** Interval Advanced, Scenario Time: 00:00:03.000 **
00:00:05.837 - AS1  : RED_ATTACK_5.14
   1    6 1    8 7 0
IFF: CG-47.1 vs BADGER_1.8: unknown by interrogation of enemy
   TRK: CG-47.1 updated track on BADGER_1.8.
   1    6 1   15 7 0
IFF: CG-47.1 vs RED_ATTACK_6.15: unknown by interrogation of enemy
   TRK: CG-47.1 updated track on RED_ATTACK_6.15.
   1    6 1   13 7 0
IFF: CG-47.1 vs RED_ATTACK_4.13: unknown by interrogation of enemy
   TRK: CG-47.1 updated track on RED_ATTACK_4.13.
   1    6 1    9 7 0
IFF: CG-47.1 vs BADGER_2.9: unknown by interrogation of enemy
   TRK: CG-47.1 updated track on BADGER_2.9.
   1    6 1   18 7 0
IFF: CG-47.1 vs RED_STRIKE_1.18: unknown by interrogation of enemy
   TRK: CG-47.1 updated track on RED_STRIKE_1.18.
  14    6 1   13 7 0
** Interval Advanced, Scenario Time: 00:00:06.000 **
00:00:08.000 - FSAM1: CG-47.1
00:00:08.435 - AS1  : RED_STRIKE_1.18
   1    9 1    8 7 0
   TRK: CG-47.1 updated track on BADGER_1.8.
   1    9 1   15 7 0
   TRK: CG-47.1 updated track on RED_ATTACK_6.15.
   1    9 1   13 7 0
   TRK: CG-47.1 updated track on RED_ATTACK_4.13.
   1    9 1    9 7 0
   TRK: CG-47.1 updated track on BADGER_2.9.
   1    9 1   18 7 0
   TRK: CG-47.1 updated track on RED_STRIKE_1.18.
  14    9 1   13 7 0
** Interval Advanced, Scenario Time: 00:00:09.000 **
00:00:09.000 - FSAM1: CG-47.1
00:00:09.359 - AS1  : BADGER_1.8
00:00:09.621 - AS1  : BADGER_2.9
00:00:10.000 - FSAM1: CG-47.1
00:00:11.000 - FSAM1: CG-47.1
00:00:11.160 - AS1  : RED_ATTACK_6.15
   RED_ATTACK_1.2 activated at time  - 00:00:11.999
   ENGAGE: RED_ATTACK_1.2 activated
   1   12 1    8 7 0
   TRK: CG-47.1 updated track on BADGER_1.8.
   1   12 1   14 7 0
IFF: Target RED_ATTACK_5.14 is squawking.
IFF: CG-47.1 vs RED_ATTACK_5.14: unknown by interrogation of enemy
   TRK: CG-47.1 initiated track on RED_ATTACK_5.14.
   1   12 1   15 7 0
   TRK: CG-47.1 updated track on RED_ATTACK_6.15.
   1   12 1   13 7 0
   TRK: CG-47.1 updated track on RED_ATTACK_4.13.
   1   12 1    9 7 0
   TRK: CG-47.1 updated track on BADGER_2.9.
   1   12 1    2 7 0
```

APPENDIX F

The following list of registered EADSIM users was provided by the U.S. Army Missile Command (MICOM) EADSIM User Services Office. It lists all currently registered EADSIM users as of 26 May 1993, the point of contact for the organization, and their address. The EADSIM User Services Office maintains the user database and updates it continuously.

1 32ND AADCOM

POC: COL STONE
Addr: COMMANDER
32D AADCOM
ATTN AETL-GC-PL (MAJ WILSON)
APO NY 09175

2 AERONAUTICAL SYSTEMS CENTER, DEVELOPMENT PLANNING

POC: TONY KIM
Addr: ASC/XREC
BLDG 11A
1970 3RD STREET SUITE 2
ATTN TONY KIM
WPAFB OH 45433-7209

3 AERONAUTICAL SYSTEMS CENTER - ELECTRONIC COMBAT SYSTEMS PROGRAM OFFICE

POC: WILLIAM E. LYONS
Addr: ATTN WILLIAM E. LYONS
ASC/RWXE BLDG 28
2145 THIRD STREET
WRIGHT PATTERSON AFB, OH 45433-7017

4 AERONAUTICAL SYSTEMS CENTER/RANGE SYSTEMS PROGRAM OFFICE

POC: Capt. Tom Connare
Addr: ATTN CAPT CONNARE
ASC/YIEJ
EGLIN AFB FL 32540

5 AFIT/ENG

POC: Dr. Thomas Hartrum
Addr: AFIT/ENG
ATTN TOM HARTRUM
WRIGHT-PATTERSON AFB OH 45433-6583

6 AFSAA/SAG

POC: Lt Col Frederic T Case
Addr: AFSAA/SAG
ROOM 1D380 (LT COL CASE)
PENTAGON
WASHINGTON DC 20330

7 AIR DEFENSE LIASON TEAM

POC: LTC Anderson
Addr: AIR DEFENSE LIASON TEAM KOREA
(FKJ3-OP-ADA) UNIT NUMBER 15237
APO AP 96205-0010
ATTN LTC ANDERSON

8 AIR FORCE ELECTRONIC WARFARE CENTER - VULNERABILITY ANALYSIS DIVISION (SAV)

POC: Capt. Troy Caudle
Addr: AFEWC/SAV
ATTN CAPT CAUDLE
SAN ANTONIO TX 78243-5000

9 AIR FORCE WARGAMING CENTER

POC: Mr. Kenneth E. Lavoie
Addr: AUCADRE/WG
ATTN KEN LAVOIE
BLDG 1406
MAXWELL AFB AL 36112-5532

10 AIWS PROJECT OFFICE NAVAL AIR WARFARE CENTER - WEAPONS DIVISION

POC: Dale Knutsen
Addr: COMMANDER (CODE C28P)
NAVAL AIR WARFARE CENTER - WEAPONS DIVISION
ATTN DALE KNUTSEN
CHINA LAKE CA 93555-6001

---

11 ARINC RESEARCH CORPORATION

POC: Elizabeth Thomson
Addr: ARINC RESEARCH CORPORATION
2551 RIVA ROAD
ATTN ELIZABETH THOMSON
ANNAPOLIS MD 21401

---

12 ARL

POC: MAJ MacAllister
Addr: ARMY RESEARCH LAB
ATTN AMSRL-WT-WA (MAJ MACALLISTER)
APG MD 21005-5066

---

13 ARMSTRONG LAB HUMAN ENGINEERING - WRIGHT PATTERSON AFB

POC: Gilbert Kupperman
Addr: AL/CFHI
ATTN GILBERT KUPPERMAN
WRIGHT-PATTERSON AFB OH 45433-6573

---

14 ASI

POC: Michelle Kilikauskas
Addr: ASI
ATTN MICHELLE KILIKAUSKAS
825 NORTH DOWNS
RIDGECREST CA 93555

---

15 BATTELLE MEMORIAL INSTITUTE

POC: Fred Rea
Addr: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
ATTN FRED REA
COLUMBUS OH 43201-2693

---

16 BDM

POC: Margaret Dellinger
Addr: BDM INTERNATIONAL INC
950 EXPLORER BLVD
ATTN MARGARET DELLINGER
HUNTSVILLE AL 35806

---

17 BOEING AEROSPACE AND ELECTRONICS

POC: Gene Bruce
Addr: BOEING DEFENSE AND SPACE GROUP
ATTN GENE BRUCE
P O BOX 3999
MAIL STOP 8Y-61
SEATTLE, WA 98124-2499

---

18 BOOZ ALLEN

POC: Ben Johnson
Addr: BOOZ ALLEN
ATTN BEN JOHNSON
1525 PERIMETER PARKWAY
SUITE 300
HUNTSVILLE AL 35806-1685

19 BOOZ ALLEN & HAMILTON INC.

POC: Michael P. Stromberg
Addr: BOOZ ALLEN & HAMILTON INC
ATTN MICHAEL P STROMBERG
8283 GREENSBORO DRIVE
ROOM 635
MCLEAN VA 22102

20 CAE-LINK

POC: Dennis Miller
Addr: LINK FLIGHT SIMULATION DIVISION
PO BOX 1237
ATTN DENNIS MILLER
BINGHAMTON NY 13902

21 CAS, INC

POC: Fred Sharp
Addr: CAS INC
650 DISCOVERY DRIVE
PO BOX 11190
ATTN FRED SHARP
HUNTSVILLE AL 35814

22 CENTER FOR NAVAL ANALYSIS

POC: Peter Dezendorf
Addr: CENTER FOR NAVAL ANALYSIS
ATTN PETER DEZENDORF
4401 FORD AVENUE
ALEXANDRIA VA 22302

23 CENTRAL INTELLIGENCE AGENCY

POC: Thomas Donahue
Addr: CIA/OSWR
ATTN TOM DONAHUE
WASHINGTON DC 20505

24 CINCPAC FLT

POC: Dr. Ray Runyan
Addr: COMMANDER IN CHIEF UNITED STATES PACIFIC FLEET
ATTN DR. RAY RUNYAN
P O BOX 6
BLDG 250 ROOM 202 CODE N53
PEARL HARBOR HI 96860-7000

25 COLSA

POC: Donna Painter
Addr: COLSA CORPORATION
ATTN DONNA PAINTER
6726 ODYSSEY DRIVE
HUNTSVILLE AL 35806

26 CORPS SURFACE-TO-AIR MISSILE PROJECT MANGAGEMENT OFFICE

POC: BOB SHACKELFORD
Addr: PROGRAM EXECUTIVE OFFICE
GLOBAL PROTECTION AGAINST LIMITED STRIKES
ATTN SFAE-GPL-SM-E(SHACKELFORD)
P.O. BOX 1500
REDSTONE ARSENAL AL 35807-3801

27 CRC

POC: Krista Givens
Addr: COLEMAN RESEARCH CORPORATION
6820 MOQUIN DRIVE
ATTN KRISTA GIVENS
HUNTSVILLE AL 35806

28 CRC

POC: Jackie Rose
Addr: COLEMAN RESEARCH CORPORATION
990 EXPLORER BLVD
SUITE A
ATTN: JACKIE ROSE
HUNTSVILLE AL 35806

---

29 DARPA

POC: James T. Silverthorn
Addr: DARPA/ADI
ATTN JAMES SILVERTHORN
4001 NORTH FAIRFAX DRIVE
CEXEC SUITE 410
ARLINGTON VA 22203

---

30 DCSOPS

POC: Dan Cunningham
Addr: DEPARTMENT OF THE ARMY
DEPUTY CHIEF OF STAFF FOR OPERATIONS AND PLANS (DAMO-MOIA)
PENTAGON (ATTN DAN CUNNINGHAM)
WASHINGTON DC 20310-0410

---

31 DECISION SCIENCE APPLICATIONS

POC: Kathie Reece
Addr: ATTN KATHIE REECE
1755 TELSTAR RD
SUITE 201
COLORADO SPRINGS CO 80920

---

32 DESE RESEARCH, INC.

POC: Frederick W. Chiverton
Addr: DESE
ATTN FREDERICK CHIVERTON
2700 TRIANA BLVD
HUNTSVILLE AL 35805

---

33 DET 4, USAF AWC

POC: Lt. Kevin Nyberg
Addr: DETACHMENT 4
USAF AIR WARFARE CENTER
ATTN LT NYBERG
BLDG 20361
KIRTLAND AFB NM 87117-5617

---

34 DIA

POC: Bill Flemming
Addr: DIAC(DB-1/PMO)
ATTN: BILL FLEMMING
BOLLING AIR FORCE BASE
WASHINGTON DC 20340-6575

---

35 DIO

POC: Dan Haggerty
Addr: DIO
ATTN ECAC/IITRI(HAGGERTY)
185 ADMARAL COCHERANE DRIVE
ANNAPOLIS MD 21401

---

36 DYNETICS, INC.

POC: Bill Haines
Addr: DYNETICS INC
PO DRAWER B
ATTN BILL HAINES
HUNTSVILLE AL 35814-5050

37 EL PASO ANALYTICS

POC: Steven Chavez
Addr: EL PASO ANALYTICS
ATTN STEVEN CHAVEZ
7750 ALABAMA ST #B
EL PASO TX 79904-3136

---

38 ELECTROSPACE SYSTEMS

POC: G. V. McWilliams
Addr: ELECTROSPACE SYSTEMS
PO BOX 831359
ATTN MAIL STATION 2800 (G V MCWILLIAMS)
RICHARDSON TX 75083-1359

---

39 FASTC

POC: CAPT ROBERT COLLINS
Addr: FASTC/TAAE
ATTN CAPT ROBERT COLLINS
WRIGHT-PATTERSON AFB OH 45433-6508

---

40 FLIGHT CONTROL DIVISION

POC: Jack Barry
Addr: WL/FIGS
ATTN JACK BARRY
WPAFB OH 45433-6553

---

41 GENERAL DYNAMICS - CONVAIR

POC: Bob Stewart
Addr: HUGHES AIRCRAFT CORP - MISSILE SYSTEMS DIV
ATTN: BOB STEWART MZ 36-6000
PO BOX 85357
SAN DIEGO CA 92138

---

42 GENERAL RESEARCH CORPORATION

POC: Tom Chapman
Addr: GENERAL RESEARCH CORPORATION
635 DISCOVERY DRIVE
ATTN TOM CHAPMAN
HUNTSVILLE AL 35806

---

43 GENERAL RESEARCH CORPORATION

POC: Brendan Callahan
Addr: GENERAL RESEARCH CORPORATION
ATTN BRENDAN CALLAHAN
1900 GALLOWS ROAD
VIENNA VA 22182

---

44 GEO DYNAMICS

POC: Pam Littleton
Addr: GEO DYNAMICS
ATTN PAM LITTLETON
5450 TECH CENTER DRIVE #230
COLORADO SPRINGS CO 80919

---

45 GEORGIA TECH RESEARCH INSTITUTE

POC: James Green
Addr: GTRI/HRL
PO BOX 9162
ATTN JIM GREEN
HUNTSVILLE AL 35812-0162

46 HQ AFOTC

POC: Capt Venton Duncan
Addr: HQ AFOTC / SAN
ATTN CAPT DUNCAN
8500 GIBSON BLVD
KIRTLAND AFB NM 87117-5558

---

47 HUGHES AIRCRAFT COMPANY - L.A.

POC: Jim Soash
Addr: HUGHES AIRCRAFT COMPANY
ATTN JIM SOASH
PO BOX 45066
LOS ANGELES CA 90045-0066

---

48 IITRI

POC: Dana Frost
Addr: ECAC/IITRI
185 ADMIRAL COCHRAN DRIVE
ANNAPOLIS MD 21401

---

49 JBL COX ENTERPRISES

POC: Jerry Cox
Addr: JBL COX ENTERPRISES
9 LAKE LORRAINE CIRCLE
ATTN JERRY COX
SHALIMAR FL 32579

---

50 JOHN HOPKINS UNIVERSITY

POC: Lou Gieszel
Addr: JOHN HOPKINS UNIVERSITY
APPLIED PHYSICS LAB
ATTN LOU GIESZEL
JOHN HOPKINS ROAD
LAUREL MD 20723-6099

---

51 JOINT STAFF - FORCE STRUCTURE, RESOURCES AND ASSESSMENT

POC: LCDR LIZ STERNAMAN
Addr: THE JOINT STAFF
ATTN LCDR STERNAMAN
ASD/ROOM 1D929
THE PENTAGON
WASHINGTON DC 20318-8000

---

52 LAWRENCE LIVERMORE NATIONAL LABORATORY

POC: Al Kaufman
Addr: LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: DR. ALFRED M. KAUFMAN
MS L-85
7000 EAST AVENUE
LIVERMORE, CA 94550

---

53 LOCKHEED AERONAUTICAL SYSTEMS COMPANY

POC: M. R. Doody
Addr: LOCKHEED AERONAUTICAL SYSTEMS COMPANY
ATTN M. R. DOODY
86 SOUTH COBB DRIVE
DEPT 73-D4 ZONE 0685
MARIETTA GA 30063

---

54 LOCKHEED, FT WORTH

POC: Anthony D. Lewis
Addr: LOCKHEED, FT WORTH
PO BOX 748
ATTN ANTHONY D. LEWIS
FT WORTH TX 76101

55 LOCKHEED MISSILES AND SPACE

POC: Dr. Ed Dobbins
Addr: LOCKHEED MISSILES AND SPACE
ATTN: ED DOBBINS
PO BOX 070017
HUNTSVILLE AL 35807-0717

---

56 LOCKHEED MISSILES AND SPACE COMPANY

POC: Ken Triebes
Addr: LOCKHEED MISSILES AND SPACE
PO BOX 3504
ATTN KEN TRIEBES
SUNNYVALE CA 94088-3504
ORG/66-80 BLDG 586W

---

57 MARTIN MARIETTA AERO & NAVAL SYSTEMS

POC: A.J. Whittle
Addr: MARTIN MARIETTA AERO & NAVAL SYSTEMS
ATTN: A J WHITTLE M/S E-522
103 CHESAPEAKE PARK PLAZA
BALTIMORE MD 21220

---

58 MARTIN MARIETTA ELECTRONICS SYSTEMS

POC: Roger Shope
Addr: MARTIN MARIETTA ELECTONICS SYSTEMS
ATTN ROGER SHOPE
PO BOX 628007/MP 1072
ORLANDO FL 32862-8007

---

59 MARTIN MARIETTA - ORLANDO

POC: Thomas Horrigan
Addr: MARTIN MARIETTA
PO BOX 5837
MAIL POINT 560
ATTN THOMAS HORRIGAN
ORLANDO FL 32855-5837

---

60 MCDONNEL DOUGLAS

POC: Roy Thrasher
Addr: MCDONNEL DOUGLAS
ATTN ROY THRASHER
689 DISCOVERY DRIVE
HUNTSVILLE AL 35806

---

61 MCDONNELL AIRCRAFT COMPANY

POC: Ed Duddy
Addr: MCDONNELL AIRCRAFT COMPANY
DPRO ENGINEERING OFFICE
ATTN ED DUDDY
MAIL CODE 2704409 PO BOX 516
ST LOUIS MO 63166

---

62 MICOM RD&EC ASCO

POC: DAVID E. MERCHANT
Addr: HQ
US ARMY MISSILE COMMAND
ATTN: AMSMI-RD-ST(MERCHANT)
REDSTONE ARSENAL, AL 35898-5242

---

63 MITRE - BEDFORD

POC: Dorothy Pedersen
Addr: THE MITRE CORPORATION
BURLINGTON ROAD
MS 1302
ATTN DOROTHY PEDERSEN
BEDFORD MA 01730

64 NATIONAL TEST BED JOINT PROGRAM OFFICE

POC: Kathy Stempeck
Addr: NATIONAL TEST BED JOINT PROGRAM OFFICE
ATTN KATHY STEMPECK
FALCON AFB, CO 80912-5000

---

65 NAVAL AIR WARFARE CENTER - AIRCRAFT DIVISION

POC: DONALD DAVIS
Addr: COMMANDER
NAVAL AIR WARFARE CENTER(CODE 3021)
AIRCRAFT DIVISION WARMINSTER
PO BOX 5152
WARMINSTER PA 18974-0591

---

66 NAVAL AIR WARFARE CENTER - WEAPONS DIVISION

POC: Harold Okamoto
Addr: COMMANDER (CODE C2813)
NAVAL AIR WARFARE CENTER - WEAPONS DIVISION
CHINA LAKE CA 93555-6001

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Addr: ATTN LCDR NEIL BOURASSA
NAVAL POSTGRADUATE SCHOOL
SMC #2985
MONTEREY CA 93943

---

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POC: MIKE McCANN
Addr: COMPUTER CENTER CODE 51
ATTN MIKE MCCANN
VISUALIZATION LAB
NAVAL POSTGRADUATE SCHOOL
MONTEREY CA 93943

---

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POC: James A. Ballas
Addr: NAVAL RESEARCH LABORATORY
JAMES A BALLAS
CODE 5534
WASHINGTON DC 20375-5337

---

70 NAVAL STRIKE WARFARE CENTER

POC: MAJ KEVIN SCOTT
Addr: NAVAL STRIKE WARFARE CENTER, BLDG 465
ATTN CODE 92
NAVAL AIR STATION
FALLON, NV 89496-5000

---

71 NAVAL SURFACE WARFARE CENTER

POC: Aaron Goldfarb
Addr: NAVAL SURFACE WARFARE CENTER
10901 NEW HAMPSHIRE AVENUE
ATTN AARON GOLDFARB(CODE A41)
(MS CODE D25)
SILVER SPRINGS MD 20903-5000

---

72 NAVAL SURFACE WARFARE CENTER - CODE 4032

POC: Brent Waggoner
Addr: COMMANDER
NAVAL SURFACE WARFARE CENTER
300 HWY 361
ATTN BRENT WAGGONER CODE 4032 BUILDING 3212
CRANE IN 47522-5050

73 NAVAL SURFACE WARFARE CENTER - DAHLGREN DIVISION

POC: SUZANNE FORSLING
Addr: COMMANDER
ATTN N24/SUZANNE FORSLING
DAHLGREN DIVISION
NAVAL SURFACE WARFARE CENTER
DAHLGREN VA 22448-5000

---

74 NCCOSC

POC: Gary Carlson
Addr: NCCOSC
NRAD CODE 852(CARLSON)
271 CATALINA BLVD
SAN DIEGO CA 92152-5132

---

75 NICHOLS RESEARCH

POC: Mike Pendley
Addr: NICHOLS RESEARCH
P.O. BOX 400002
4040 SOUTH MEMORIAL PARKWAY
ATTN MIKE PENDLEY
HUNTSVILLE AL 35802

---

76 NORTHROP B-2 DIVISION, ADVANCED PROJECTS

POC: Charles T. Case
Addr: NORTHROP B-2 DIVISION
ATTN CHARLES CASE
DEPT T211/GB
8900 EAST WASHINGTON BLVD
PICO RIVERA CA 90660-3737

---

77 NORTHROP CORPORATION, ADVANCED TECHNOLOGY AND DESIGN CENTER

POC: Karen Arriaza
Addr: NORTHROP CORPORATION
ATTN KAREN ARRIAZA
DEPT N410 ZONE GG
8900 EAST WASHINGTON BLVD
PICO RIVERA CA 90660-3737

---

78 NTF SPECIAL PROGRAMS CENTER

POC: Capt Dennis E. Nihiser
Addr: DIRECTOR NTF SPECIAL PROGRAMS CENTER
ATTN NIHISER
NTF/PDT
730 IRWIN AVE
FALCON AFB CO 80912-7300

---

79 OFFICE OF AEROSPACE STUDIES AIR FORCE SYSTEMS COMMAND

POC: Capt. Kevin P. Haupt
Addr: OAS/AFMC
ATTN CAPT KEVIN HAUPT
KIRTLAND AFB NM 87117

---

80 OFFICE OF THE DEPUTY ASSISTANT SECRETARY (STRATEGIC PROGRAMS)

POC: Maj Michael Bruhn
Addr: OSD (PA&E) SD&SP
ROOM 2E286 THE PENTAGON
WASHINGTON DC 20301-1800

---

81 OLBB

POC: TSGT GARY ZIMMERMAN
Addr: GARY ZIMMERMAN
1958 SCOTT DRIVE SUITE 6
ELSWORTH AFB SD 57706-4710

82 OSD STUDIES AND ANALYSIS DIVISION

POC: MAJ WILLIAM TARANTINO
Addr: MAJOR TARANTINO / JNGO / ME670
DEFENSE SYSTEMS SUPPORT ORG
7010 PENTAGON
WASHINGTON D.C. 20301 - 7010

---

83 PEO GPALS, ATMDPO

POC: SAM LAIL, JR.
Addr: PEO, GPALS
ATTN SFAE-GPL-TMD-SI-B (LAIL)
PO BOX 1500
HUNTSVILLE AL 35807-3801

---

84 PHILLIPS LABORATORY

POC: Lt. David Van Veldhuizen
Addr: LT DAVID VAN VELDHUIZEN
PHILLIPS LABORATORY/WST
3550ABERDEEN AVE SE
KIRTLAND AFB NM 87117-5776

---

85 PLESSEY

POC: Paul Markwardt
Addr: PLESSEY ELECTRONICS SYSTEMS CORPORATION
15 JACKSON ROAD
ATTN PAUL MARKWARDT MS 08A40
TOTOWA NJ 07512

---

86 QUANTUM

POC: Jerry Rawlinson
Addr: QUANTUM RESEARCH INC
4717 UNIVERSITY DRIVE
EXECUTIVE PLAZA SUITE #100
ATTN JERRY RAWLINSON
HUNTSVILLE AL 35816

---

87 RAND

POC: DR. GREGORY BORN
Addr: RAND
ATTN DR. BORN
1700 MAIN STREET
SANTA MONICA CA 90407-2138

---

88 RAYTHEON COMPANY - HUNTSVILLE

POC: Richard K. Queeney
Addr: RAYTHEON COMPANY
353 JAMES RECORD ROAD
ATTN RICHARD K. QUEENEY
HUNTSVILLE AL 35824

---

89 RAYTHEON COMPANY -TEWKSBURY

POC: Dr. Howard
Addr: RAYTHEON COMPANY
MISSILE SYSTEMS DIVISION
50 APPLE HILL DR.
ATTN DR HOWARD (T3TG6)
TEWKSBURY MA 01876

---

90 RDEC

POC: Julie Ellerbeck
Addr: COMMANDER
US ARMY MISSILE COMMAND
ATTN AMSMI-RD-SS-SE(EADSIM)
REDSTONE ARSENAL AL 35898-5252

91 RJO/POET

POC: Frank Handler
Addr: FRANK HANDLER
RJO-POET
1225 JEFFERSON DAVIS HIGHWAY
SUITE 300
ARLINGTON VA 22202

---

92 RJO/POET

POC: David C. Eissler
Addr: RJO/POET
ATTN DAVID C. EISSLER
1745 JEFFERSON DAVIS HIGHWAY
SUITE 1100
ARLINGTON, VA 22202

---

93 SAIC - ARLINGTON

POC: Jim Meagher
Addr: CEXEC
4001 NORTH FAIRFAX DRIVE
SUITE 410
ATTN JIM MEAGHER
ARLINGTON VA 22203

---

94 SAIC- EL PASO

POC: Bob Penry
Addr: SAIC
7400 VISCOUNT BVLD
SUITE 220
ATTN BOB PENRY
EL PASO TX 79925

---

95 SAIC - (JPL)MCLEAN

POC: John P. Lawerence
Addr: SAIC/MS1-6-2
ATTN JOHN LAWERENCE/E. SIMPSON
1710 GOODRIDGE DRIVE
MCLEAN VA 22102

---

96 SAIC - (RA)MCLEAN

POC: Richard Aldridge
Addr: SAIC
ATTN RICHARD ALDRIDGE
1710 GOODRIDGE DRIVE
MAIL STOP T2-8-1
MCLEAN VA 22102

---

97 SOFTWARE ENGINEERING DIRECTORATE

POC: CAMILLA GEAN
Addr: COMMANDER
US ARMY MISSILE COMMAND
ATTN: AMSMI-RD-BA
REDSTONE ARSENAL, AL 35898-5260

---

98 SPARTA CORPORATION

POC: Wai Lee
Addr: SPARTA
ATTN WAI LEE
7926 JONES BRANCH DRIVE
SUITE 900
MCLEAN VA 22102-3303

---

99 SPARTA, INC.

POC: John Segrest
Addr: SPARTA INC
4901 CORPORATE DRIVE
ATTN JOHN SEGREST
HUNTSVILLE AL 35805

100 STWES-ID-T

POC: DR. RAUL MACHUCA
Addr: COMMANDER
US ARMY WHITE SANDS MISSILE RANGE
ATTN STEWS-ID-TA(DR. MACHUCA)
WHITE SANDS MISSILE RANGE NM 88002-5144

---

101 SUMMA TECH

POC: Tom Shpakowsky
Addr: SUMMA TECH
ATTN TOM SHPAKOWSKY
500 DISCOVERY DRIVE
HUNTSVILLE AL 35806

---

102 SVERDRUP TECHNOLOGY INC

POC: Pete Mahon
Addr: SVERDRUP TECHNOLOGY INC
ATTN PETE MAHON
626 ANCHOR STREET NW
SUITE 4
FORT WALTON BEACH FL 32548

---

103 TBE

POC: BRAD COOPER
Addr: TELEDYNE BROWN ENGINEERING
300 SPARKMAN DRIVE
PO BOX 070007
ATTN BRAD COOPER
HUNTSVILLE AL 35807-7007

---

104 TEC-MASTERS, INC

POC: Mike Burns
Addr: TEC-MASTERS INC
ATTN MIKE BURNS
1500 PERIMETER PARKWAY
SUITE 320
HUNTSVILLE AL 35806

---

105 TERNION

POC: Craig Korpela
Addr: TERNION CORPORATION
3307 BOB WALLACE AVENUE SUITE 1
ATTN CRAIG KORPELA
HUNTSVILLE AL 35805

---

106 THE AEROSPACE CORPORATION

POC: John R. Shure
Addr: THE AEROSPACE CORPORATION
ATTN JOHN SHURE
PO BOX 92957
EL SEGUNDO CA 90009-2957

---

107 TRW - HUNTSVILLE

POC: Don Owens
Addr: TRW
213 WYNN DRIVE
ATTN DON OWENS
HUNTSVILLE AL 35805

---

108 TRW - REDONDO BEACH

POC: Joseph Swartz
Addr: TRW (ATTN JOSEPH SWARTZ)
APPLICATIONS TECHNOLOGY DIVISION
MAIL STOP R1-1032
1 SPACE PARK
REDONDO BEACH CA 90278

109 U. S. ARMY CONCE.?TS ANALYSIS AGENCY

POC: Pam Roberts
Addr: U S ARMY CONCEPTS ANALYSIS AGENCY
ATTN PAM ROBERTS
8120 WOODMONT AVENUE
BETHESA MD 20814-2797

---

110 U.S. ARMY MATERIAL SYSTEMS A\ ALYSIS ACTIVITY - AIR WARFARE DIVISION

POC: Scott Phillips
Addr: U.S. ARMY MATERIAL SYSTEMS ANALYSIS ACTIVITY
ATTN AMXSY-ADH(PHILLIPS)
ABERDEEN PROVING GROUNDS MD 21005-5071

---

111 U.S. STRATCOM

POC: Lee Jaramillo
Addr: J534
US STRATCOM
ATTN LEE JARAMILLO
901 SAC BLVD SUITE 2E8
OFFUTT AFB NE 68113-6500

---

112 UNITED STATES AIR FORCE AIR COMPONENT COMMAND - JOINT STUDIES GROUP

POC: Capt. Hal Sommer
Addr: HQ ACC/XP-JSG/FD
ATTN: CAPT. HAL SOMMER
756 DURAND ROAD
LANGLEY AFB VA 23665-2595

---

113 UNITED STATES ARMY STRATEGIC DEFENSE COMMAND

POC: MAJ TIM McKAIG
Addr: DEPUTY COMMANDER
USASDC
ATTN CSSD-SA-SD(MAJ TIM MCKAIG)
PO BOX 1500
HUNTSVILLE AL 35807-3801

---

114 US AIR FORCE MATERIEL COMMAND, ESC/XRPM

POC: Capt. Curt Signorino
Addr: ESC/XRPM
ATTN CAPT SIGNORINO
HANSCOM AFB MA 01731-1624

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115 US ARMY ARMAMENT RESEARCH DEVELOPMENT & ENGINEERING CENTER (ARDEC)

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US ARMY ARDEC
ATTN SMCAR-FSS-E(ANGELOTTI)
PICATINNY ARSENAL NJ 07806-5000

---

116 US NAVAL POSTGRADUATE SCHOOL - OPERATIONS RESEARCH DEPT

POC: LCDR M.R. Rios
Addr: LCDR M.R. RIOS, USN
C/O OPS RESEARCH CIRRICULUM OFFICE
NAVAL POSTGRADUATE SCHOOL
MONTEREY CA 93940

---

117 USAADASCH (ATSA-CDF-M)

POC: Ray Cartwright
Addr: COMMANDANT
USAADASCH
ATTN ATSA-CDF-M (RAYMOND CARTWRIGHT)
FORT BLISS TX 79916-0002

118 USAF TAWC - EGLIN

POC: CPT Chilcott
Addr: OSD JADO/JEZ JT&E JTF
ATTN CPT CHILCOTT
EGLIN AFB FL 32542-5000

---

119 USAF TAWC - HURLBURT

POC: LTC CLUSKEY
Addr: 4441ST TACTICAL TRAINING GROUP
ATTN LTC CLUSKEY
HURLBURT FIELD FL 32544

---

120 USAF/XOXWF

POC: CPT Christopher Hines
Addr: HQ USAF/XOXWF
ATTN CPT CHRISTOPHER HINES
BF 922B
WASHINGTON DC 20330

---

121 USAFE

POC: MAJ Folson
Addr: HQ USAFE/DOJW
ATTN MAJ FOLSON
RAMSTEIN AB GE
APO AE 09094

---

122 VEDA

POC: Bill McNellis
Addr: VEDA INC
5200 SPRINGFIELD PIKE
SUITE 200
ATTN BILL MCNELLIS
DAYTON OH 45431

---

123 W.J. SCHAFER ASSOCIATES

POC: Libby Jordan
Addr: WJ SCHAFER ASSOCIATES
ATTN LIBBY JORDAN
1500 PERIMETER PARKWAY
SUITE 470
HUNTSVILLE AL 35806

---

124 WESTINGHOUSE ELECTRIC CORPORATION

POC: Elizabeth M. Lanier
Addr: WESTINGHOUSE ELECTRIC CORP
ATTN ELIZABETH LANIER
PO BOX 1897 MS 1765
BALTIMORE MD 21203

LIST OF REFERENCES

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6.	Major Robert Irby, USA USASSDC Test Bed Product Office Huntsville, AL 35814	1
7.	Ms. Jeannine Williams USASSDC Test Bed Product Office Huntsville, AL 35814	1

8. Mr. Dan Yates 1
Teledyne Brown Engineering
Cummings Research Park
Huntsville, AL 35814

9. Mr. Tom Dahm 1
CAS Inc.
650 Discovery Drive
P.O. Box 11190
Huntsville, AL 35814

10. Mr. David Hornick 1
AIR 5164
Naval Air Systems Command
Washington, DC 20361-5160

11. LCDR Neil R. Bourassa 1
Naval Electronics System Engineering Center
Portsmouth, VA 23709-5000